SEWAGE AND INDUSTRIAL WASTES

(Formerly Sewage Works Journal)

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

Special Features

Fundamentals of Oxygen Transfer—Ippen and Carver

Electroplating Wastes—Walker et al.

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JULY, 1954—VOL. 26, No. 7

Make Plans to Attend

27TH ANNUAL MEETING

OF THE

FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

IN CONJUNCTION WITH

OHIO SEWAGE AND INDUSTRIAL WASTES TREATMENT CONFERENCE

NETHERLAND PLAZA HOTEL
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October 11-14, 1954

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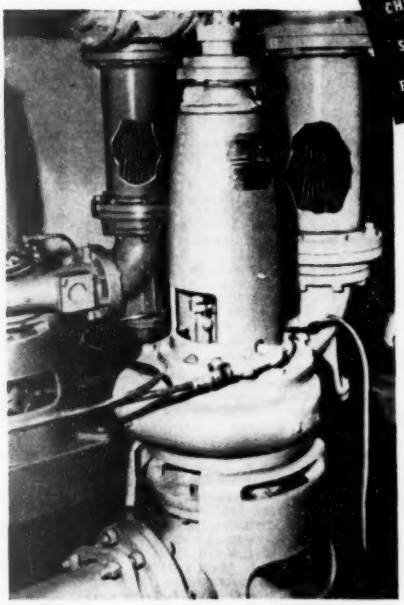

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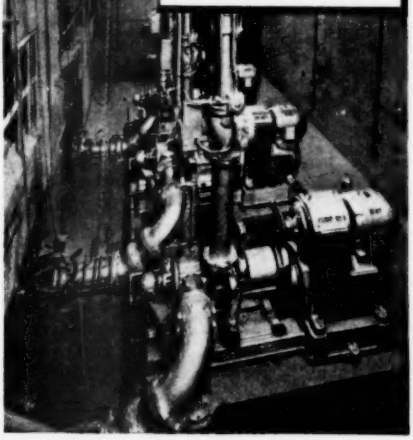

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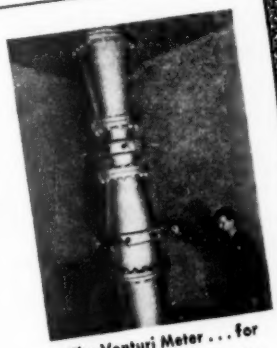

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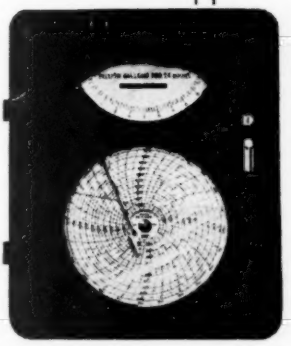

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Association	*Place*	*Time*
Pennsylvania Sewage and Industrial Wastes Assn.	The Pennsylvania State College, State College, Pa.	Aug. 25–27, 1954
Iowa Sewage Works Assn.	Hotel Russell-Lampson, Waterloo, Iowa	Sept. 14–16, 1954
Kentucky-Tennessee Industrial Wastes and Sewage Works Assn.	Andrew Jackson Hotel, Nashville, Tenn.	Sept. 20–22, 1954
North Dakota Water and Sewage Works Conf.	Hotel Dakota, Grand Forks, N. D.	Sept. 22–24, 1954
Georgia Water and Sewage Assn.	Georgia Institute of Technology, Atlanta, Ga.	Sept. 22–24, 1954
Missouri Water and Sewage Conf.	Hotel Governor Jefferson City, Mo.	Sept. 26–28, 1954
South Dakota Water and Sewage Works Conf.	Lawler Hotel Mitchell, So. Dak.	Sept. 28–30, 1954

TWENTY-SEVENTH ANNUAL MEETING

Federation of Sewage and Industrial Wastes Associations
in conjunction with
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Netherland Plaza Hotel, Cincinnati, Ohio
October 11–14, 1954

Pacific Northwest Sewage and Industrial Wastes Assn.	Hotel Eugene Eugene, Oregon	Oct. 21–23, 1954
Canadian Institute on Sewage and Sanitation	Windsor Hotel Montreal, P. Q. Can.	Oct. 25–27, 1954
New England Sewage and Industrial Wastes Assn.	Hotel Stratfield, Bridgeport, Conn.	Oct. 28, 1954
Rocky Mountain Sewage Works Assn.	Broadmoor Hotel, Colorado Springs, Colo.	Nov. 8–10, 1954
Florida Sewage and Industrial Wastes Assn.	Sorrento Hotel, St. Petersburg, Fla.	Nov. 8–10, 1954
North Carolina Sewage and Industrial Wastes Assn.	George Vanderbilt Hotel, Asheville, N. C.	Nov. 8–10, 1954
West Virginia Sewage and Industrial Wastes Assn.	Hotel Prichard, Huntington, West Va.	Nov. 9–10, 1954
Nebraska Sewage and Industrial Wastes Assn.	Keystone Hotel, McCook, Nebraska	Nov. 11–12, 1954
Oklahoma Water, Sewage and Industrial Wastes Conf.	Student Union Bldg., Stillwater, Okla.	Nov. 15–20, 1954

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- A revolutionary development in surface aeration which makes all other types of aeration obsolete.

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- A mechanical aeration plant and a diffused air plant operating side-by-side for 15 years—same sewage, equal effluents—showed these average annual costs of maintenance repairs and renewals per million gallons—mechanical aeration.... 18 cents—diffused air....98 cents.
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- Hi-Cone surpasses the best records of diffused air plants as to 5-day BOD and suspended solids reduction *with an equal aeration period.*
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A view of Lake Street, Chicago, as it looked 100 years ago.

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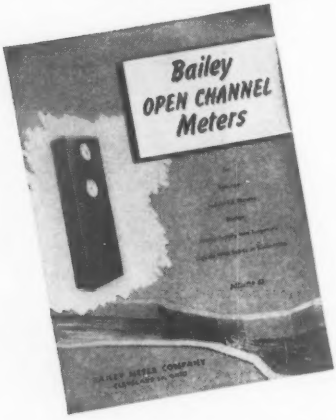

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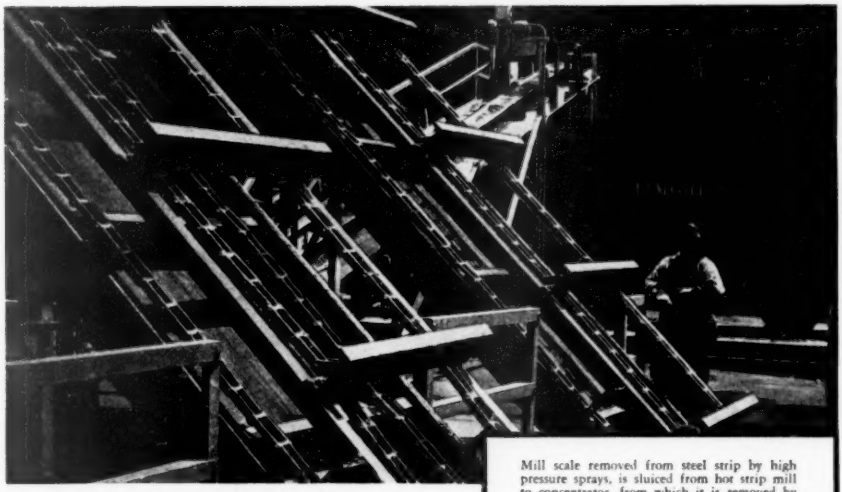

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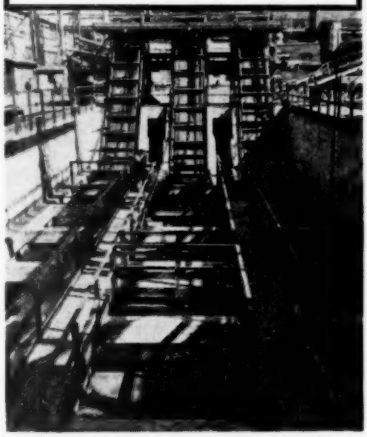

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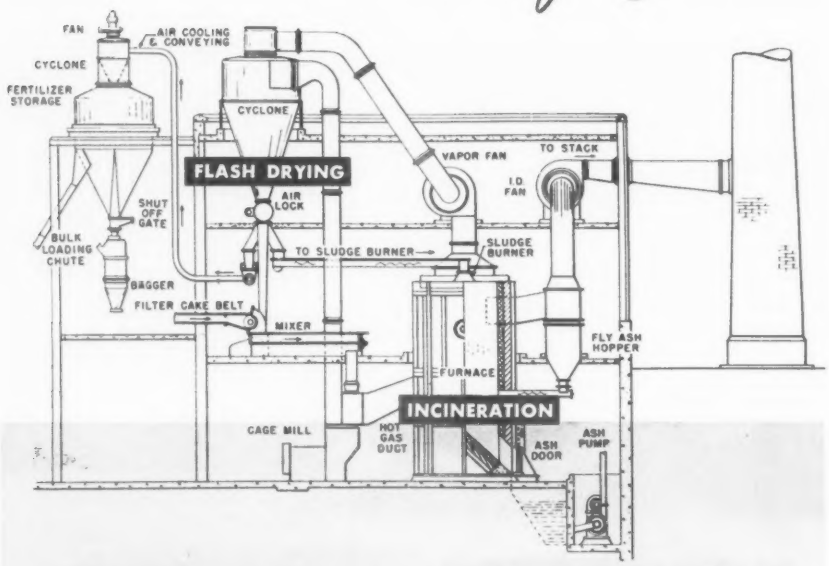

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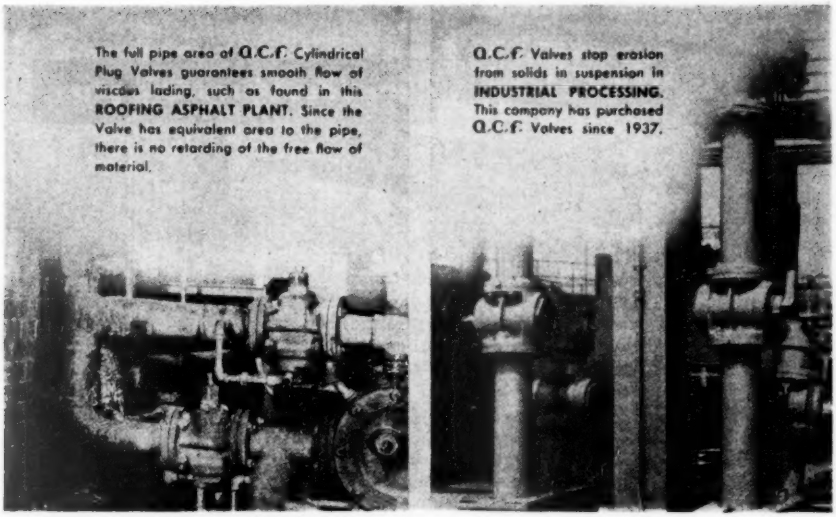
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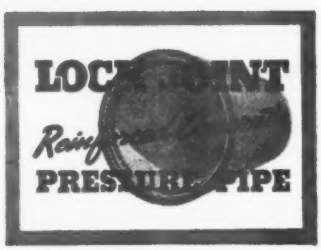

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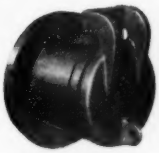

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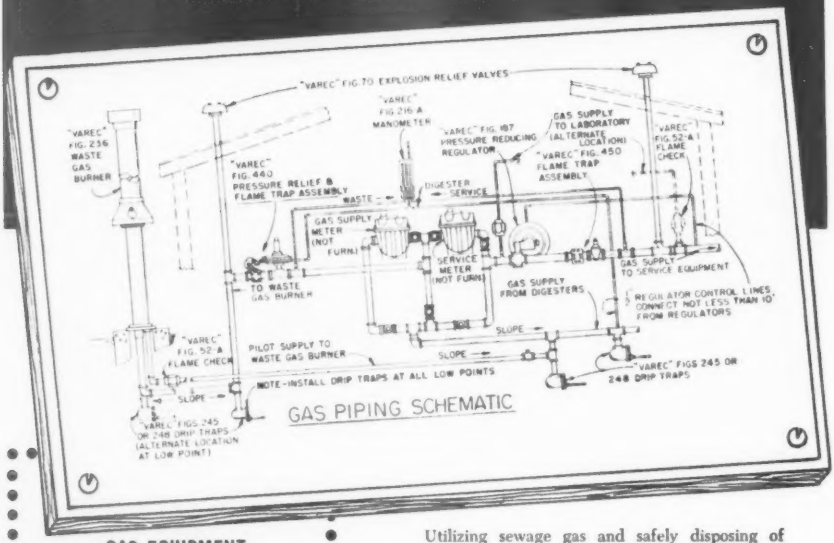
"VAREC" FIG. 70 EXPLOSION RELIEF VALVES
"VAREC" FIG. 216 A MANOMETER
"VAREC" FIG. 187 PRESSURE REDUCING REGULATOR
GAS SUPPLY TO LABORATORY (ALTERNATE LOCATION)
"VAREC" FIG. 450 FLAME TRAP ASSEMBLY
"VAREC" FIG. 52 A FLAME CHECK
"VAREC" FIG. 236 WASTE GAS BURNER
"VAREC" FIG. 440 PRESSURE RELIEF & FLAME TRAP ASSEMBLY
DIGESTER SERVICE
WASTE
GAS SUPPLY METER (NOT FURN.)
SERVICE METER (NOT FURN.)
GAS SUPPLY TO SERVICE EQUIPMENT
TO WASTE GAS BURNER
GAS SUPPLY FROM DIGESTERS
REGULATOR CONTROL LINES CONNECT NOT LESS THAN 10" FROM REGULATORS
"VAREC" FIG. 52 A FLAME CHECK
PILOT SUPPLY TO WASTE GAS BURNER
SLOPE
SLOPE
SLOPE
NOTE-INSTALL DRIP TRAPS AT ALL LOW POINTS
"VAREC" FIGS 245 OR 248 DRIP TRAPS
"VAREC" FIGS 245 OR 248 DRIP TRAPS (ALTERNATE LOCATION AT LOW POINT)
GAS PIPING SCHEMATIC

GAS EQUIPMENT SPECIFICATIONS

PRESSURE RELIEF AND FLAME TRAP ASSEMBLY
"VAREC" Fig. No. 440

FLAME TRAP ASSEMBLY
"VAREC" Fig. No. 450

FLAME CHECK
"VAREC" Fig. No. 52A

EXPLOSION RELIEF VALVES
"VAREC" Fig. No. 70-1

WASTE GAS BURNER
"VAREC" Fig. No. 236

DRIP TRAPS
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MANOMETERS
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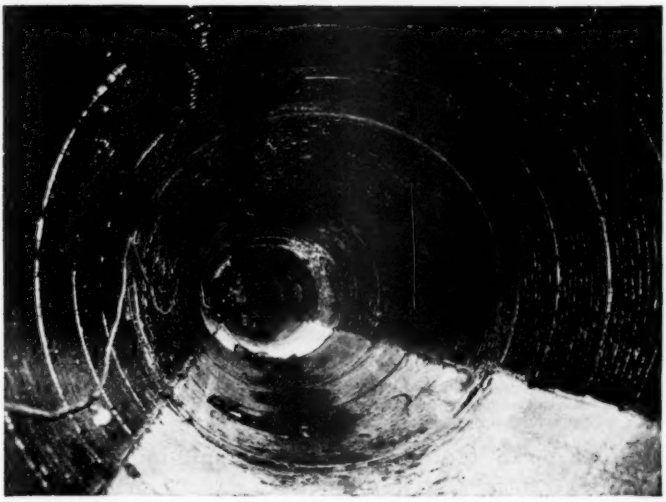
Are Your Sewers Failing?

Note distorted crown of the old brick sewer.



Armco ASBESTOS-BONDED Corrugated Pipe in relined Milwaukee sewer. PAVED-INVERT protects against erosion.

You won't know unless you look. Failing sewers often keep their secret until it is too late.

In Milwaukee, inspection showed an old 96-inch combined brick sewer was at the point of failure. Various materials were considered for the repair job, but Armco ASBESTOS-BONDED Sewer Pipe was finally selected. It was strong, corrosion-resistant and its installation would not disturb the existing structure or materially reduce the waterway area. The pipe was installed in 8- to 20-foot lengths, reducing the number of joints required. Costs were low and the work went fast.

Armco Corrugated Metal Pipe is also widely used for new sanitary and storm sewers as a safeguard against future trouble and expense. Why not write us today for details? And don't forget about planning an inspection for your present sewer. It may save trouble later on. Armco Drainage & Metal Products, Inc., 1274 Curtis Street, Middletown, Ohio. Subsidiary of Armco Steel Corporation.

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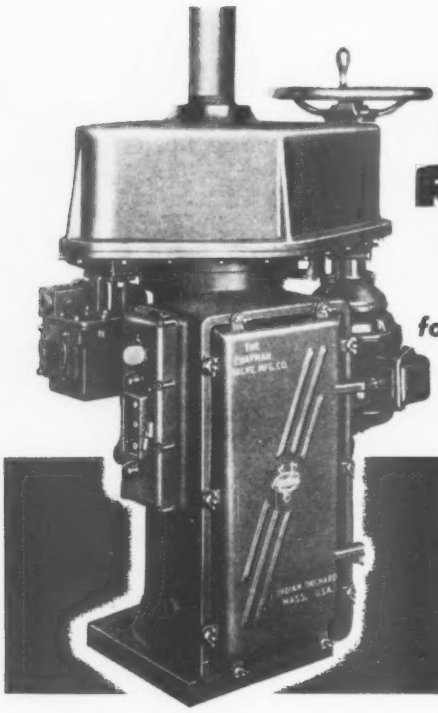

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CHAPMAN'S MOTOR UNIT

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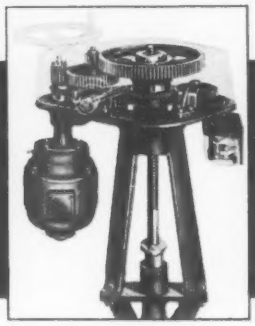

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Weatherproof and steam tight, Chapman's floorstand units are shipped completely wired, ready to connect to your power leads, for easy, rapid installation. This modern motor unit is dependable and economical. Send for *new* catalog No. 51.

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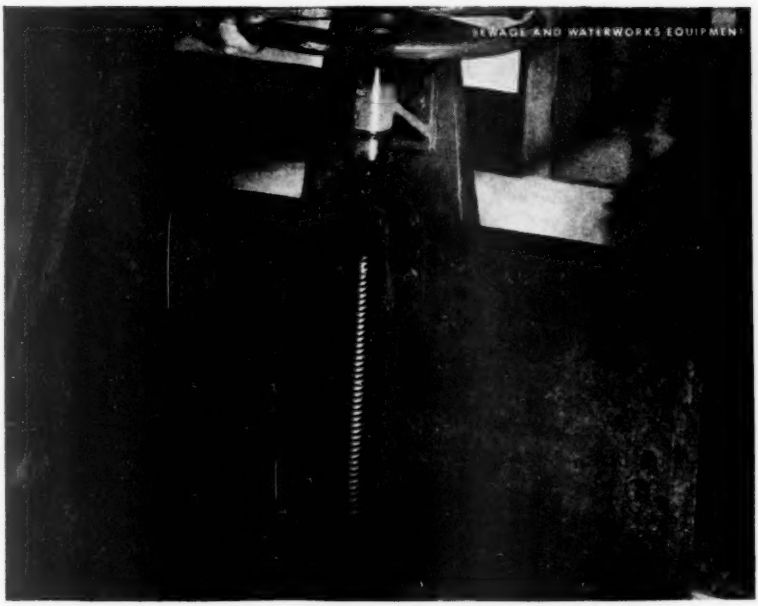

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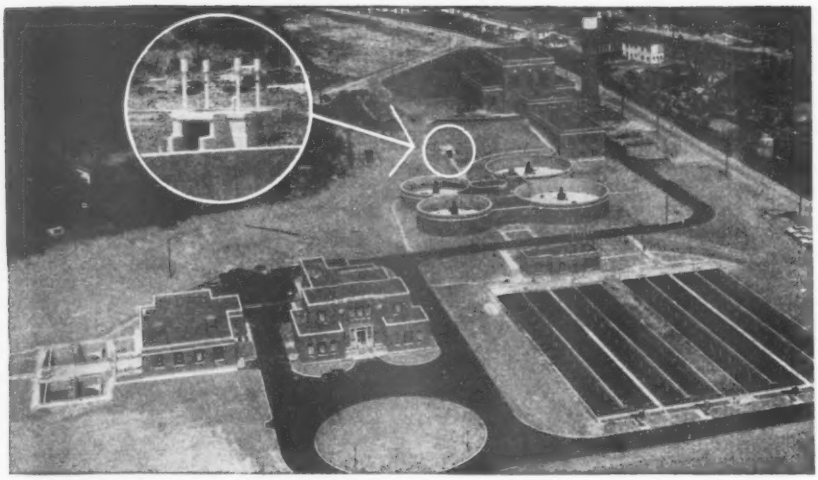

At Arlington County, Virginia . . .

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In 1953, fast growing Arlington County expanded its capacity in a *practical* way by:

(1) converting its two 50′ tanks to secondary digestors
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The result: P.F.T. "Controlled Digestion" and a new capacity of 20,000,000 gallons per day—4 times the capacity of its former design!

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P.F.T. Floating Covers reduce costly breakdowns and repairs by eliminating all moving parts inside the digestor.

With its new equipment, Arlington soon found its gas production exceeding all requirements. This excess gas is safely handled by P.F.T. gas control equipment, including four 3″ waste gas burners mounted on a separate structure as shown in the illustration above.

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SEWAGE AND INDUSTRIAL WASTES

Journal of the Federation of Sewage and Industrial Wastes Associations

Volume 26 | **July, 1954** | **Number 7**

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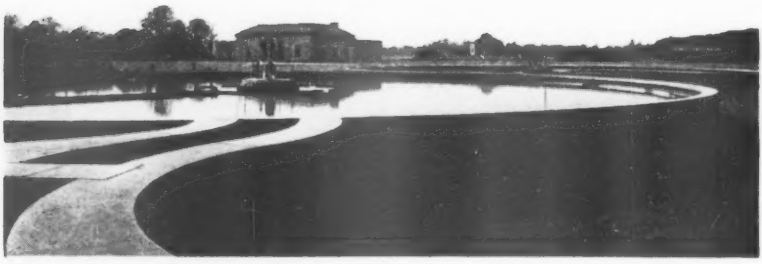
Figures Tell the Story about the Low Maintenance Costs with DORR CLARIFIERS



...and the Baltimore Sewage Treatment Plant is a typical **Case In Point...**

16 years ago the Baltimore Department of Public Works installed its first two center-drive Dorr Clarifiers. Since then, 4 additional units have been added. The figures below tell the actual repair costs story. They are not "exceptions to the rule" but are typical of the low maintenance costs of Dorr Clarifiers reported by city after city.

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Number of Units	Size of Clarifiers	Years of Operation	Repair Parts Cost*			Repairs as % of	
			Total	Per Unit	Per Unit Per Year	Original Cost	Original Cost Per Year
2	170 ft. Diameter	16	$241.40	$120.70	$7.55	1.08	0.068
1	170 ft. Diameter	15	no repair costs to date				
2	126 ft. Diameter	14	168.20	84.10	6.01	0.95	0.068
1	170 ft. Diameter	3	no repair costs to date				

*includes modest unsegregated labor costs

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Sewage Works

BASIC FACTORS OF OXYGEN TRANSFER IN AERATION SYSTEMS *

By Arthur T. Ippen and Charles E. Carver, Jr.

Hydrodynamics Laboratory, Massachusetts Institute of Technology, Cambridge, Mass.

Previous Investigations

A mathematical analysis of the mechanism of diffusion of a gas bubble at rest in a liquid-gas solution with a uniform concentration of dissolved gas has been presented by Epstein and Plesset (2). These investigators have shown, for instance, that 208 min. are required for a bubble of 1-mm. diameter to be completely absorbed when stationary.

In a report by Pekeris (3) on the other hand, it is shown that even minute velocities of the order of 0.01 cm. per sec. greatly increase the diffusion rate of a moving bubble over that of a stationary bubble, and that the radius decreases uniformly with time. However, since a bubble rising freely in a column of water is in contact with the liquid for a few seconds only under practical conditions of aeration, this decrease is usually negligible.

Experiments by Adeney and Becker (4), Ledig and Weaver (5), Scouller and Watson (6), Redding (7), and Zdonik (8) have brought to light some salient facts relevant to the mechanism of absorption. Adeney and Becker observed a linear increase in the absorption coefficient with temperature owing to the lower viscosity of the water, and found that a greater volume of gas was absorbed by distilled water than by sea water at the same flow rate. Scouller and Watson investigated the absorption of oxygen from air bubbles 2.4 mm. in diameter, and found that the amount of oxygen absorbed by means of bubble aeration was three times that absorbed through an unagitated free surface. Redding and Zdonik concluded from their investigations that oxygen, nitrogen, and carbon dioxide are less soluble in sea water than in distilled water, that the liquid-film coefficient (here termed the absorption coefficient) increases with increasing bubble diameter, increases with decrease in viscosity of the absorbing medium, and is approximately the same for the three gases investigated. Since carbon dioxide is considerably more soluble than either nitrogen or oxygen, the fact that the liquid-film coefficient was found to be very nearly the same for the three gases proves the controlling influence of the liquid film in diffusion.

Many investigations on the drag, shape, and terminal velocity of bubbles rising freely in water may be found in the literature. A recent investigation by Rosenberg (9) has shown that bubbles rising through a fluid behave like solid spheres at Reynolds numbers less than 70, but deviate from solid spheres in shape, drag, and terminal velocity as the Reynolds number increases (see also Figure 3).

Theoretical Relations

The equation which expresses the amount of oxygen absorbed by bubble

* Presented at 26th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Miami, Fla.; Oct. 13–16, 1953.

diffusion may be written as

$$O = \int_0^t K A (C_i - C_L)\, dt \ldots (1)$$

in which

O = oxygen absorbed, in pounds;
A = total interfacial contact area of bubbles, in square feet;
C_i = equilibrium concentration of oxygen at the gas-liquid interface, in p.p.m.;
C_L = concentration of oxygen in the liquid at any time t, in p.p.m.; and
K = over-all coefficient of oxygen absorption, based on liquid film resistance, in pounds of oxygen per hour per square foot per unit concentration difference (p.p.m.).

The amount of oxygen absorbed, in pounds, may also be expressed as

$$O = \frac{W}{10^6}(C_t - C_0) = \frac{W}{10^6}\int_0^t \frac{(\partial C)}{(\partial t)}\, dt \cdots (2)$$

in which

W = weight of water in aeration column, in pounds;
C_t = concentration of oxygen in liquid at the end of time t, in p.p.m.; and
C_0 = initial concentration of oxygen in liquid, in p.p.m.

Eqs. 1 and 2, therefore, give

$$\frac{dC}{dt} = \frac{10^6 KA}{W}(C_i - C_L) \ldots . (3)$$

Setting the limits $C = C_0$ when $t = 0$ and $C = C_L$ when $t = t$ and integrating, yields

$$\log_{10}\frac{(C_i - C_0)}{(C_i - C_L)} = \frac{10^6 KAt}{2.3\,W} \cdots (4)$$

The equilibrium concentration, C_i, is calculated from the relationship

$$C_i = \frac{0.21\,Pq'}{760}\left(\frac{1 - p_v/P}{1 - p_v/760}\right) \quad \text{for air bubbles} \ldots (5a)$$

$$C_i = \frac{Pq'}{760}\left(\frac{1 - p_v/P}{1 - p_v/760}\right) \quad \text{for oxygen bubbles} \ldots (5b)$$

in which

P = total pressure at midpoint of column, equal to barometric pressure in mm. Hg + $\frac{1}{2}$ column height in mm. Hg;
p_v = aqueous vapor pressure, in mm. Hg, at the test temperature;
q' = solubility of oxygen at the given temperature (11), expressed in p.p.m., where the partial pressure of the gas plus aqueous tension is 760 mm. Hg.

The similarity between Eq. 3 and those describing the flow of heat or electricity is quite apparent. The driving force $(C_i - C_L)$ is comparable to a temperature or potential difference, whereas the coefficient K may be looked upon as the reciprocal of a resistance and hence a conductance.

In stating Eq. 3, the following assumptions were made:

1. The gas follows the Perfect Gas Law.
2. The bubbles are spherical.
3. Isothermal conditions prevail.
4. The excess bubble pressure due to the surface tension is negligible.
5. There is no appreciable change in the surface contact area of the bubbles.
6. C_i remains constant during the bubble ascent.

The extent to which these assumptions hold is discussed later.

Equipment and Experimental Procedure

A schematic representation of the test equipment is given in Figure 1. Air from a laboratory compressor or oxygen from a cylinder entering the system is reduced in pressure by means of a reducing valve to about 20 p.s.i. gage. It then passes through a filter to remove dust or other impurities and is washed in a humidifying tank. The tank serves the double purpose of further cleaning the air and saturating it with water vapor to prevent that component from diffusing into the

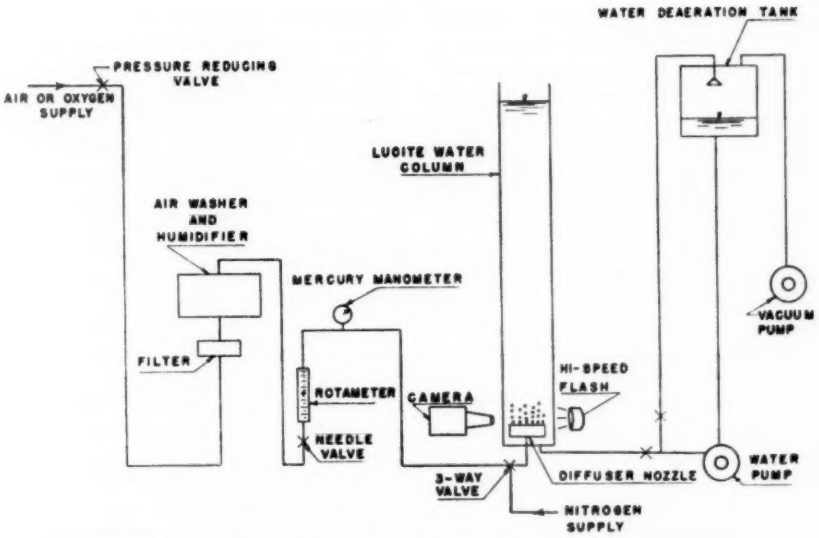

FIGURE 1.—Schematic diagram of test apparatus for the determination of oxygen absorption.

bubble upon release in the aeration column. The gas flow is accurately metered by means of a rotameter, to which an open U-tube mercury manometer is attached. It is then admitted to the column through a specially constructed diffuser nozzle. The nozzle consists of 19 glass capillary tubes cut in 1-in. lengths from marine barometer tubing. These tubes are imbedded in a ½-in. thick rubber disc having 19 uniformly spaced holes to provide a uniform bubble dispersion in the column. The disc is then sandwiched between two aluminum plates and screwed to a circular housing, which is fastened to the air inlet of the column. The column itself was made of lucite, having an inside diameter of 5.5 in. and a wall thickness of 0.25 in. It was composed of several sections, each 52 in. in length and flanged at both ends so that various depths could be obtained by bolting them together.

To provide an initially low concentration of dissolved oxygen prior to the commencement of a test, water was circulated through a vacuum tank equipped with a spray nozzle (Figure 1). This partially deaerated water was then pumped into the aeration column, where the D.O. content was further reduced by "stripping" by means of nitrogen bubbles introduced into the column through a three-way valve and the diffuser. When the D.O. content was reduced in this manner to about 0.2 p.p.m., the test was started with the admittance of air or oxygen to the column. The test was terminated as soon as the column became saturated with dissolved oxygen.

Frequent D.O. determinations were made during a run by extracting water samples from the column and analyzing them by means of the Winkler test. This method was used throughout for pure oxygen bubbles. In the case of air bubbles, the dissolved oxygen content was determined both by Winkler analysis and by means of a mercury dropping electrode and graphic recording device (1). The mercury dropping electrode was limited to D.O. values less than 20 p.p.m. and to relatively low gas flow rates; the latter limitation was due to the fact that the turbulence generated by the bubbles at the higher

air flow rates interfered with the formation of mercury drops at the electrode.

Bubble sizes were obtained photographically by means of the set-up shown in Figure 1. A specially constructed camera having a short focal length was focused on an individual capillary and the exposure made by a high-intensity flash of about 60 microseconds duration through the use of an Edgerton Strobolume located on the side opposite the camera. The motion of bubbles emerging from the capillary was effectively stopped by this method. The resulting negative was then enlarged to yield a magnification factor of about 25 to 1, and the size of the bubble was scaled from the photograph against the diameter of the glass capillary as a standard. Terminal velocities were obtained by timing the ascent of the bubbles between two points marked off on the column. For the range of bubble sizes employed, the upward motion was essentially rectilinear, although a slight helical motion was observed for the larger bubble sizes.

Discussion of Results

Basic Assumptions

It is well here to comment upon the validity of the assumptions previously mentioned regarding the development of the diffusion equation. The assumption of essentially isothermal conditions is reasonable, since the temperature of the gas and of the surrounding liquid differed but slightly. Perfect gas behavior may be taken as justified in view of the order of magnitude of the pressures and temperatures which prevailed. The excess pressure within a bubble due to surface tension was found to be negligible in comparison to the pressure normally existing within bubbles of this size, and was therefore neglected. For bubbles in the Stokes range and smaller, however, the surface tension pressure would be large and would have to be taken into account. Few bubbles emerging from a capillary were truly spherical, but were observed to have the shape of oblate spheroids. In this case, the diameter of the bubble was calculated as the diameter of an equivalent sphere having the same volume as the bubble. Deviations from a spherical shape were not great, however, for the bubble sizes employed.

With regard to the instantaneous contact area of bubbles in the column, it is apparent that the assumption of a constant surface is questionable in two respects; the surface area increases due to expansion during the rise of the bubble to the water surface, while at the same time the absorption of oxygen will cause a decrease in surface area. The two effects are thus compensatory in character. However, their relative influence on the area change for the two gases investigated must be more clearly defined. In an attempt to account for expansion, the mean of the volume rates of flow calculated in accordance with the isothermal pressure-volume relationship for the pressure conditions at the top and bottom of the column was used to determine a mean bubble size. The effect of absorption on the bubble volume is variable with time, exerting the greatest influence at low initial D.O. concentrations and becoming negligible as saturation is approached. In addition, this influence is considerably more pronounced for oxygen than for air bubbles at low D.O. concentrations and in some instances more than compensates for the increase due to expansion.

The procedure for determining the mean surface contact area when oxygen bubbles were used was to evaluate the average percentage of oxygen transferred from the time of commencement of a test to the time of saturation. The bubble size corrected for expansion was then adjusted to account for this average oxygen loss. The mean surface area was computed for the adjusted bubble size and used in the calculation for K. The value of K thus computed represents an average for the entire period of aeration, and does not reflect

the influence of temporal variation in surface area.

Where aeration was carried out with air, the bubble sizes were corrected for expansion as before, the resulting volume then being adjusted for the maximum rate of oxygen absorption existing initially. This latter refinement was of little consequence in comparison with the expansion effect which was the predominant factor influencing the surface area.

It remains to consider the effects of absorption and expansion on C_i, which was assumed to remain constant in the derivation of the diffusion equation. To account in part for the change in the equilibrium concentration due to expansion, it was calculated for an average pressure at the midpoint of the column in accordance with Eq. 5a and 5b. For pure oxygen bubbles it is clear that the absorption of oxygen from the bubble will not alter the partial pressure of the gas and, hence, has no influence on C_i. With air bubbles, however, absorption will cause a continual lowering of the partial pressure of oxygen within the bubble. The effect on C_i is again most pronounced at low initial concentrations and becomes insignificant near saturation concentrations.

For the calculations of K with air bubbles, the equilibrium concentration C_i was assumed unaffected by oxygen absorption, as a more rational and practical procedure of correction could not readily be devised. It is realized that the calculation of the effect of absorption on C_i for air bubbles should ultimately be refined, and that the absorption coefficient K for air as stated is valid only under the preceding assumption.

Solution of Eq. 4 for K gives

$$K = \frac{2.3\,W}{10^6\,A\,t}\left[\log_{10}\frac{(C_i - C_0)}{(C_i - C_L)}\right] \cdots (6)$$

Figure 2 shows a typical oxygenation curve (curve A) obtained from an aeration experiment using oxygen bub-

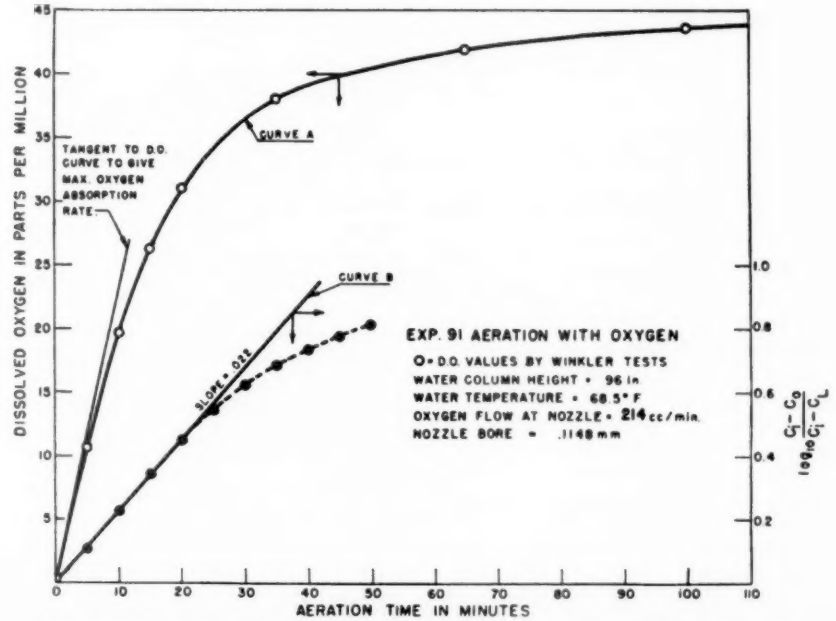
DISSOLVED OXYGEN IN PARTS PER MILLION
AERATION TIME IN MINUTES
TANGENT TO D.O. CURVE TO GIVE MAX. OXYGEN ABSORPTION RATE
CURVE A
CURVE B
SLOPE = $K_{2.2}$
EXP. 91 AERATION WITH OXYGEN
O = D.O. VALUES BY WINKLER TESTS
WATER COLUMN HEIGHT = 96 in
WATER TEMPERATURE = 68.5° F
OXYGEN FLOW AT NOZZLE = 214 cc/min.
NOZZLE BORE = .1148 mm
$\log_{10}\frac{C_i - C_0}{C_i - C_L}$

FIGURE 2.—Typical aeration curve (curve A) using oxygen bubbles, with semi-logarithmic plot (curve B) of relative concentration.

bles. Shown also is a semi-logarithmic plot of relative concentration (curve B). The latter curve is obtained by calculating the logarithmic term of Eq. 4, the values of C_L for various values of t being taken from the oxygenation curve. The logarithmic term divided by t is then equal to the slope of the curve B in Figure 2. Eq. 6 thus results in

$$K = \frac{60 \times 2.3\ W \times \text{max. slope of curve B}}{A \times 10^6} \qquad (7)$$

A typical calculation to determine K is presented here for the experiment depicted in Figure 2. The pertinent data are: bubble size at the nozzle, 1.94 mm.; mean bubble size at column midpoint adjusted for absorption and expansion, 2.00 mm.; gas flow rate at the nozzle, 214 c.c. per min.; C_i calculated from Eq. 5b, 47.83 p.p.m.; column height, 96 in.; terminal velocity of bubbles, measured, 0.79 ft. per second. The calculations proceed as follows:

Volume of bubble at nozzle $= (\pi/6)(0.194)^3 = 0.00382$ c.c.

$$\text{Number of bubbles per min.} = \frac{\text{gas flow at nozzle}}{\text{vol. per bubble at nozzle}} = \frac{214}{0.00382} = 56{,}000 \text{ per min.}$$

Mean surface area per bubble $= (\pi)(d_{\text{mean}})^2 = \pi(0.2)^2 = 0.1258$ sq. cm.

Total surface area generated per minute $= 56{,}000\ (0.1258) = 7{,}050$ sq. cm. per min.

$$\text{Contact time in column} = \frac{\text{col. height}}{\text{terminal vel.}} = \frac{8}{0.79} = 10.10 \text{ sec.}$$

$$\text{Instantaneous contact area} = \frac{(\text{total area/min.})(\text{contact time})}{60} = \frac{(7{,}050)(10.10)}{60} = 1{,}185 \text{ sq. cm.} = 1.275 \text{ sq. ft.}$$

$$\text{Weight of water in column} = W = \frac{5.5^2}{4 \times 144} \times 62.4 \times 8 = 82.4 \text{ lb.}$$

Slope of curve B in Figure 2 $= 0.022$.

Thus, from Eq. 7,

$$K = \frac{60 \times 2.3 \times 82.4 \times 0.022}{1.275 \times 10^6} = 1.97 \times 10^{-4} \text{ lb. of oxygen per hour per square foot per unit of concentration difference.}$$

This value of K may be converted to units of centimeters per hour by multiplying by the conversion factor $(454/930) \times 10^6$, giving $K = 96$ cm. per hour, and is applicable to concentrations below about 15 p.p.m., as evidenced by the behavior of curve B in Figure 2.

Terminal Velocity of Gas Bubbles

Figure 3 shows a comparison between the terminal velocities as measured in this investigation with those obtained by Allen (10) and verified at the David Taylor Model Basin (9). The Allen curve was obtained for single bubbles rising freely through a column of water. In this study, however, the continuous dispersion of a large number of bubbles produced a considerable degree of turbulence and induced downward currents, with the result that the terminal velocities are somewhat less than those indicated by the Allen-DTMB curve. They are obviously dependent on the gas flow rate. It is im-

portant to note the behavior of this curve for various ranges of bubble size as it relates to the absorption process. In the range 0.6 to 4.0 mm., for example, the terminal velocity actually decreases slightly with increasing bubble size. Hence, for a given gas flow rate, one would expect that the use of larger bubbles would result in lower oxygen absorption rates due to a reduction in surface contact area. If the increase occurs in the range cited, however, an increased retention time is obtained, owing to the decrease in terminal velocity, which operates to partially compensate for the reduction in absorption rate. In contradistinction, bubbles in the range 0.1 to 0.6 mm., and greater than 4-mm. radius, exhibit increasing terminal velocities with increasing size, in which case, for a given gas flow rate, the rate of absorption suffers not only from a loss in retention time, but also from a reduction in contact area when larger bubbles are employed.

Effect of Bubble Size on Oxygen Absorption

The effect of variation in bubble size on the maximum amount of oxygen absorbed is shown in Figure 4 as a function of column height. The percentage of oxygen absorbed is obtained by dividing the pounds of oxygen absorbed per minute, based on the maximum concentration gradient existing at low initial D.O. concentrations, by the pounds of oxygen per minute supplied to the system. The flow rate along an individual curve of a given bubble size was substantially constant, but varied for curves of different bubble sizes. Because only one size capillary was used, it was not possible to vary the bubble size for a given gas flow rate and hence to obtain directly the effect of varying the bubble size on the absorption rate. Capillaries of smaller bore were subject to severe clogging, whereas larger diameters yielded bubble sizes beyond the range of this investigation.

In the following analysis, let Q be the volume rate of flow of air in cubic feet per minute, γ the specific weight of oxygen in pounds per cubic foot, and d the bubble diameter in feet, each of these quantities being calculated for conditions at the column midpoint. The percentage of oxygen absorbed of the oxygen supplied for a given concentration gradient can be expressed from Eq. 3 by multiplying both sides by $10^{-6} W/0.21\ \gamma Q$ to yield

$$\% \text{ oxygen absorbed} = \frac{KA(C_i - C_L)}{0.21\,\gamma Q} \times 100 \quad . . (8)$$

The total surface contact area A (square feet) of the bubbles in the column at any instant may be given in terms of Q, d, h, and v, wherein h is the column height in feet and v is the terminal velocity of the bubble in feet per second, which may be assumed constant with respect to h for the purpose of this discussion:

$$A = \frac{Q/60}{\pi d^3/6} \times \pi d^2 \times h/v = \frac{Qh}{10vd} \quad . . (9)$$

Substituting Eq. 9 in Eq. 8 gives

$$\% \text{ oxygen absorbed} = \frac{K(C_i - C_L)h}{10 \times 0.21\,\gamma v d} \times 100 \quad . . (10)$$

Eq. 10 also applies for oxygen bubbles if the factor 0.21 is omitted. It is seen that the flow rate does not enter into this equation. It should be remarked in accordance with findings in this work that K depends to some extent on h (see Figure 5) and on d (7), and that v will change with the number of bubbles per unit volume and with d for a given liquid. For bubble diameters from 1 to 10 mm., the velocity of rise, v, does not vary greatly with d. The desirability of decreasing the bubble diameter to approach the Stokes range is strongly suggested by Eq. 10, wherein v becomes ultimately proportional to d^2 and therefore the percentage of oxygen absorbed increases inversely with d^3. There exists, obvi-

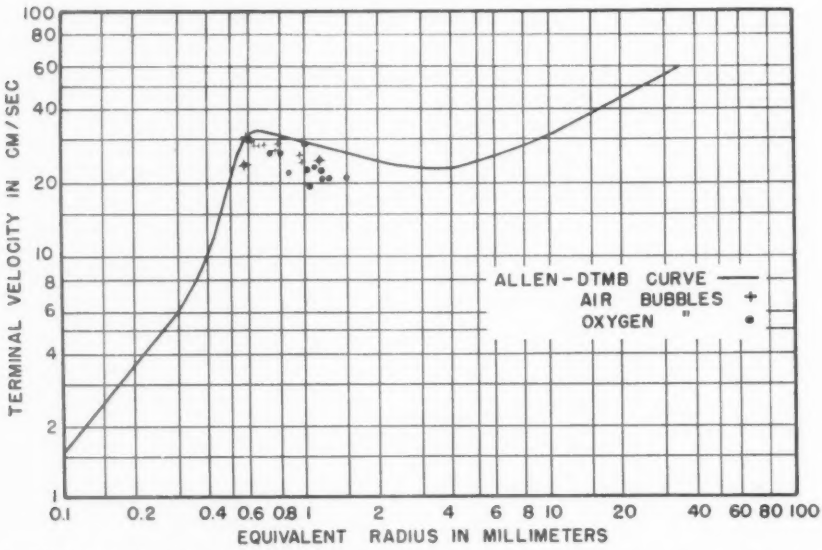

FIGURE 3.—Variation in terminal velocity with bubble radius for air and oxygen bubbles.

ously, a limiting depth h for any given bubble size within which full absorption takes place. The equation as given, however, would have to be modified with respect to the assumptions made on v, d, C_i and K before it becomes applicable to extreme conditions of almost complete oxygen absorption. Eq. 10 may also be adapted to bubble mixtures; however, further discussion is deemed outside the scope of the present paper.

In essential agreement with the preceding analysis, Figure 4 shows an increase in percentage of oxygen absorbed with decrease in bubble size for both air and oxygen bubbles for a given column height. For a given bub-

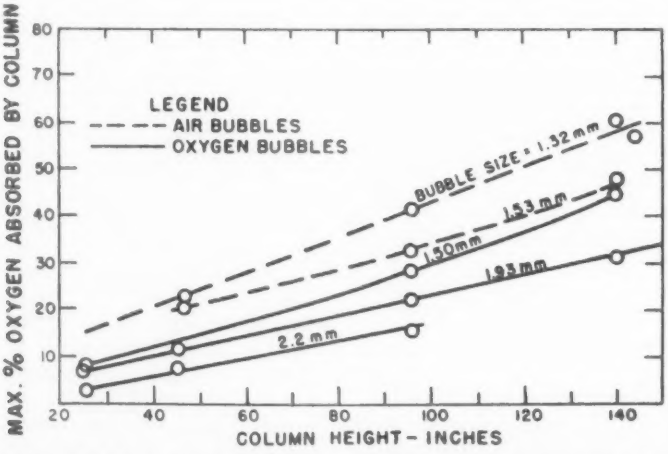

FIGURE 4.—Effect of bubble size on oxygen absorption for various column heights.

ble size the percentage of absorption increases essentially linearly with column height. This behavior is clearly connected with increased retention time. Although the various bubble sizes were in the range where an increase in size results in a slight decrease in terminal velocity the effect of the resulting increase in retention time is overshadowed by the effect of reduction in surface area on the percentage of absorption for a given flow rate when larger bubbles are employed.

Although Figure 4 indicates a higher percentage of absorption of oxygen from air bubbles as compared to pure oxygen bubbles, it must be remembered, that for a desired total oxygen transfer, the rate of flow of air would have to be increased over the flow of oxygen by a factor of 1/0.21.

Variation in K *with Column Height*

The analogy between the oxygen transfer equation and those describing the flow of heat or electricity has been previously indicated. In the latter two instances, K would correspond to a coefficient of conductance, which is a property of the material through which transfer takes place. In the case of oxygen transfer, a similar interpretation may be made; however, in this instance K becomes not a property of the gas-liquid media as such, but depends on the concentration gradients established in the liquid layer adjacent to the interface. In bubble aeration, for example, the magnitude of K represents the ability of oxygen to penetrate through the partially saturated liquid film surrounding the bubble, the characteristics of this film being a function of the rate of rise of the bubble.

In a similar manner, for the diffusion of oxygen from the atmosphere through a quiescent free surface, the value of K expresses the capacity to overcome the resistance offered by a thin layer of oxygen-saturated water at the surface. Indeed, the disruption of this layer such as is accomplished in mechanical aeration processes, will considerably increase the magnitude of K and, consequently, the net transfer of oxygen.

The variation in the liquid-film coefficient, K, as calculated from Eq. 6, with column height is shown in Figure 5 for both air and oxygen bubbles. These values are based on the maximum slope of the semi-logarithmic plot of relative concentration (curve B in Figure 2 is an example) and apply in general only for concentrations in the approximate range of 0 to 6 p.p.m. for

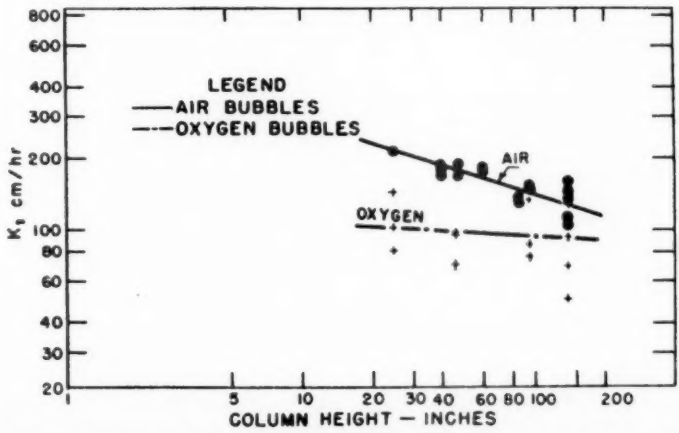

FIGURE 5.—Variation of the absorption coefficient, K, with water column height.

air bubbles and 0 to 15 p.p.m. for oxygen bubbles.

It is to be noted that the coefficient exhibits a definite downward trend with increasing column height for both gases. This trend of K as measured may be rationalized by considering the transfer of oxygen to occur in three phases, starting with the origin of the bubble at the capillary and ending with the bursting of the bubble at the interface, the intermediate phase taking place as the bubble rises through the column. The first and last phases are transient in nature, whereas the intermediate phase is characterized by a more or less steady state of transfer. It is convenient to discuss each of these modes of transfer individually in order to ascertain their effect on the behavior of K collectively.

The transient condition associated with the production of a bubble at the capillary is responsible for an unusually high rate of oxygen absorption. The reason for this is that during the formation and growth of the bubble, the liquid-gas interface surrounding the bubble is continually expanding, the concentration gradients in the liquid film remain high, and hence the resistance to diffusion is less. When the bubble has reached its full size, concentration gradients in the surrounding liquid film attain lower, stable values and thus reduced transfer of oxygen results.

The transfer after the bubble has achieved full growth remains more or less constant during the rise of the bubble to the surface. This may be termed the intermediate steady-state phase. Deviations from steady-state conditions will occur with variations in the size and rate of rise of the bubble, as previously discussed, and with the attendant effects of shear and turbulence in the bubble wake upon the liquid film.

In the final phase, the bubble bursts at the surface. The liquid layer surrounding the bubble and containing dissolved oxygen at relatively high concentrations remains as the gas escapes through the surface and is mixed with the main body of liquid. Furthermore, the disturbance of the interface by the bubble will tend to enhance the transfer of oxygen from the atmosphere. As a result of the downward currents produced by the rising bubbles, this relatively high oxygen-bearing water at the surface is carried downward into the liquid. For this reason, the distribution of oxygen over the column height is nearly uniform.

It is seen that the first and final phases of the existence of the bubble in the column are associated with higher transfer rates than occur in the steady-state phase, which remains essentially constant irrespective of column height. For this reason, therefore, the magnitude of the coefficient K must be larger at low column heights and the effect of the three phases considered collectively will be such as to decrease K with increasing column height.

Figure 5 also shows that the absorption coefficient for oxygen is less than for air at a given column height. In this connection, it should be pointed out that in the deaeration process using nitrogen, the liquid becomes saturated with this gas initially. Thus, when pure oxygen bubbles are used, the lack of a partial pressure due to nitrogen in the bubble causes nitrogen in the liquid to diffuse into the bubble. It is reasonable to conclude that this action constitutes a resistance to the diffusion of oxygen, resulting in a lower value of K for oxygen than for air at a given column height. Since the transfer of oxygen at the capillary has been shown to be large, one would similarly expect the diffusion of nitrogen into the oxygen bubble to be high in this region also, becoming of less significance as the column height increases. Based on this reasoning, the coefficients for oxygen and air bubbles should approach each other at the higher column heights, as is indeed the case in Figure 5. It is well to point out, therefore, that the values of K for oxygen bubbles apply

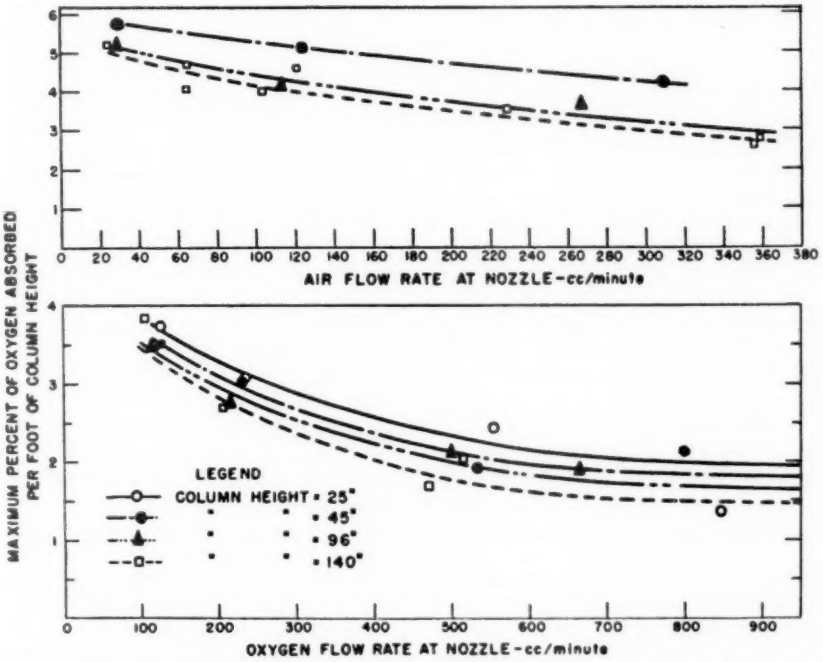

FIGURE 6.—Maximum percentage of oxygen absorbed per foot of column height as a function of flow rate for various column heights with air and oxygen bubbles.

only where the liquid is initially saturated with nitrogen.

Effect of Gas Flow Rate

The effect of the previously described trends of the absorption coefficient K is apparent also from Figure 6, which shows the maximum percentage of oxygen absorbed per foot of column height *versus* flow rate for air and oxygen for various column heights. The absorption rate is based upon the maximum concentration gradient existing at low initial D.O. concentrations. Low column heights and low flow rates are seen to yield the highest absorption percentage. The drop in percentage of absorption with increasing flow rate is probably due to the fact that for the given bore of capillary used, larger bubbles at greater frequencies resulted for increased flow rates, thus giving a greater concentration of bubbles over the vertical with relatively restricted lateral dispersion. This action is responsible for a so-called "chimney" effect, wherein the transfer of oxygen did not increase in proportion to the flow owing to the resulting increase in resistance to lateral diffusion. Passing the higher flow rates through more capillaries would probably not produce this effect as pronounced, and in addition would provide a greater surface area for transfer due to smaller bubbles.

Maximum Oxygen Concentrations as a Function of Depth

Figure 7 gives the ratios of the theoretical equilibrium concentrations C_i and of the measured final concentrations C_f in terms of the saturation concentrations C_s, as given by the International Critical Tables for the test temperatures. It should be noted that C_i was calculated for the midpoint of the column, whereas C_s applies to the

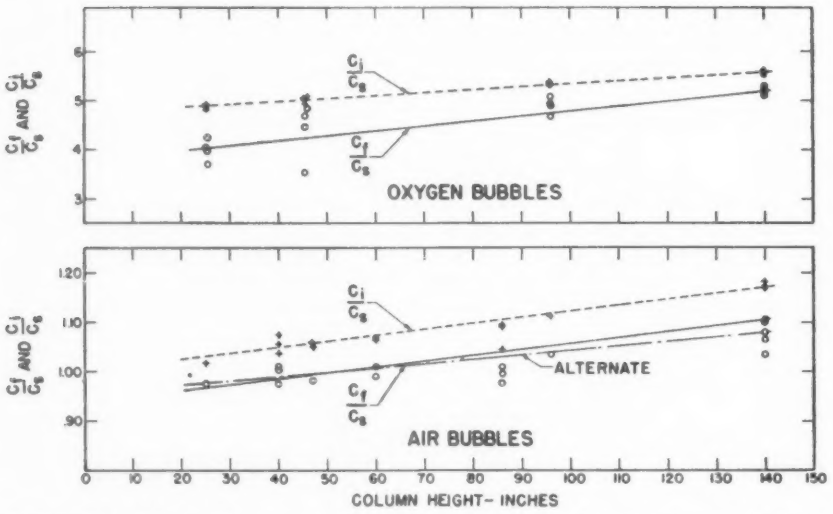

FIGURE 7.—Relations between C_i, C_f, C_s, and column height for air and oxygen bubbles.

air-water interface. It is seen that the C_f values also taken at the column midpoint remain generally lower, thus indicating a considerable loss of oxygen through the interface and the transport of surface water downward as a result of the currents engendered by the rising gas bubbles. This continuous vertical mass exchange prevents the establishment of equilibrium concentrations corresponding to C_i.

It is further seen that the ratio C_f/C_s becomes larger with increasing column heights, closely paralleling the obvious increase in C_i/C_s. For oxygen there is noted a somewhat steeper in-

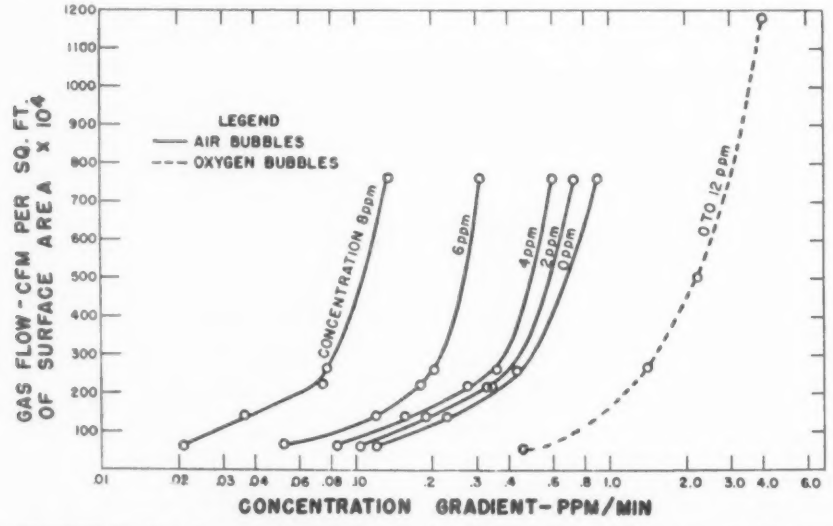

FIGURE 8.—Gas flow requirements for maintaining a given initial concentration as a function of concentration gradient.

crease in C_f/C_s. This may be due to the supersaturated conditions prevailing and the corresponding higher losses through the interface, which remain essentially constant, and therefore exert a smaller influence on ultimate average concentrations for higher column heights than for lower ones.

Gas Flow Requirements

As a first attempt at a practical implementation of the test data, Figure 8 was prepared, in which curves for several D.O. concentrations have been plotted as a function of gas flow rate per square foot of tank surface area, and of the concentration gradient. It is thus useful for obtaining approximate air or oxygen requirements necessary to maintain a desired dissolved oxygen concentration in an aeration chamber subject to a given oxygen demand. It is realized that in practice, the oxygen uptake in the activated sludge process is continually varying; however, Figure 8 does not lose its usefulness if the variation in the concentration gradient is known for a particular installation.

These curves apply only for a nozzle submerged 12 ft. for both air and oxygen, and for the corresponding value of K. Figure 8 is restricted to bubble sizes between 1.25 and 2.50 mm. dispersed essentially uniformly in the manner previously described. For air, a considerable variation is indicated in the concentration gradient, as well as in the air flow rate, for various D.O. concentration levels. By contrast, for oxygen the concentration gradient was found to be independent of the concentration level up to about 12 p.p.m.

To use the curves for air bubbles, the concentration gradient existing in a tank is evaluated, and the desired operating D.O. level is selected. The required air flow rate per unit tank surface area is then found on the ordinate scale.

The curve for oxygen gives the desired oxygen flow rate for a given concentration gradient independent of the operating D.O. level. This means that the same oxygen flow rate will satisfy a given oxygen demand at any D.O. level up to 12 p.p.m. It is seen that for air, in order to obtain a higher (or lower) D.O. level for a given concentration gradient, it is necessary to permanently increase (or decrease) the air flow rate. By contrast, for the same conditions, the oxygen flow rate in aeration with oxygen needs to be adjusted only temporarily to achieve a desired D.O. level. Once this level is reached, the oxygen flow rate can be reduced or increased to the initial value.

The curves in Figure 8 further permit certain additional conclusions with regard to aeration procedures. Each curve shows a decided break for a certain concentration gradient for every D.O. level. While it is therefore relatively easy to either increase or decrease the D.O. level with moderate adjustments of air flow rate below these breaks, air requirements to raise the D.O. level above the break tend to become excessive. Hence, if high D.O. concentrations should be desired, or if the oxygen demand is quite high, it may become advisable to furnish additional oxygen by means of pure oxygen bubbles and to use air only to the extent of providing adequate mixing. The possibility of enriched mixtures of air and oxygen also exists. The curves thus delineate clearly the range of concentration gradients which may be satisfied by aeration procedures.

Conclusions

1. For a given nozzle and a given depth the percentage of oxygen absorbed by the liquid is higher for lower gas flow rates than for higher ones. The use of an increased number of diffusers to keep the flow per nozzle at a low value is therefore desirable for higher flow rates.

2. The per cent absorption per foot of column for a given gas flow rate is higher for lower depths than for larger depths.

3. The total absorption for a given gas flow rate increases almost linearly with depth within the range employed in practice.

4. The use of more diffusers for a given gas flow rate results in the production of smaller bubbles, reduces the likelihood of coalescence, and allows better lateral diffusion through more uniform bubble dispersion. Each of these factors is favorable to increased absorption.

5. For a given column height, absorption increases with decreasing bubble size, and ultimately varies inversely with d^3 for bubbles in the Stokes range. The increased oxygen absorbed is due not only to the large surface contact area produced, but also to the increased time of retention for bubbles in this range.

6. In a given aeration system, power for compression is necessary to overcome diffuser loss and hydrostatic pressure. Absorption efficiency of oxygen is increasing with decreasing depth (from Conclusion 2), while the influence of the diffuser loss becomes relatively greater. Over-all efficiency for present practice nevertheless increases with depth until diffuser losses can be materially reduced.

7. The rate of transfer of oxygen depends greatly on the concentration level of D.O. in the liquid. A considerable increase in gas flow must be provided for a given oxygen demand if higher concentration levels are to be maintained. This suggests the possibility of either using pure oxygen for the satisfaction of the demand together with a minimum air flow to provide adequate mixing, or of using an "enriched" mixture of air and oxygen.

8. Absorption coefficients for oxygen transfer as calculated for the given aeration system decreased with increasing column height. The rate of absorption is a maximum at the point of bubble formation, and takes on lower, steady values during the rise of the bubble to the surface. The disturbance of the surface by the bursting bubbles is probably responsible for some aeration from the atmosphere.

9. The concentration of dissolved oxygen over the depth is relatively uniform as a result of the mixing currents engendered by the rising gas bubbles.

10. Values of the observed terminal velocities for both air and oxygen bubbles were somewhat less than published values for single bubbles of the same diameter. The deviation is due to secondary downward currents induced by the bubbles in their upward travel.

Acknowledgment

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DISCUSSION

By William E. Dobbins

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Although the basic principles of the transfer of gases of low solubility to liquids have been under development for a considerable period of time, it has not been possible to apply these principles to the rational design of aeration tanks because of the lack of data on the values of the over-all oxygen transfer coefficients under various conditions. This paper is an important contribution toward the goal of rational design.

For efficient aeration it is necessary to maintain a large area of gas-liquid interface per unit volume of tank, under conditions in which the coefficient of oxygen transfer, K, is also high. In mechanical aeration tanks the oxygen transfer takes place through the agitated surface area and the oxygen is carried into the body of the liquid by convection and turbulent diffusion. Although it is theoretically impossible to have this downward transfer take place without having a concentration gradient in the tank, the turbulent mixing is usually so great that very little gradient is required to provide for a rate of downward transfer equal to the rate of absorption at the surface. Hence, the oxygen concentration remains fairly uniform throughout the depth and approaches the concentration, C_s, corresponding to the partial pressure of the oxygen in the atmosphere.

In diffused air tanks the total area through which oxygen transfer takes place is the sum of the areas of the agitated water surface and the surfaces of the rising bubbles. The final concentration which is approached is higher than C_s because of the greater average pressure in the rising bubbles. The direction of the transfer of oxygen across the surface of the tank must change when the oxygen concentration in the liquid reaches C_s. Whenever the concentration in the liquid is lower than C_s the oxygen transfer across the surface of the tank is into the liquid and is aiding the aeration process. On the other hand, after the concentration becomes greater than C_s the oxygen transfer across the tank surface is from

the liquid into the atmosphere. For this reason the final concentration can never reach that corresponding to the average bubble pressure, as is shown in Figure 7. This fact may be demonstrated mathematically as follows:

If K_S = coefficient of transfer across the tank surface in cm. per hr.,
K_B = coefficient of transfer across the bubble area in cm. per hr.,
A_S = surface area in square centimeters,
A_B = bubble area in square centimeters,
and V = volume of liquid in cubic centimeters.

Eq. 3 can be modified to read:

$$\frac{dc}{dt} = \frac{K_B A_B}{V}(C_i - C_L) + \frac{K_S A_S}{V}(C_S - C_L) \quad (11)$$

Eq. 11 can be integrated to:

$$\log_{10}\left[\frac{K_B A_B (C_i - C_0) + K_S A_S (C_S - C_0)}{K_B A_B (C_i - C_L) + K_S A_S (C_S - C_L)}\right] = 0.434\, t\, \frac{K_B A_B + K_S A_S}{V} \quad (12)$$

At the final equilibrium the net rate of oxygen transfer is zero, hence from Eq. 11 it follows that:

$$-K_B A_B (C_i - C_f) = K_S A_S (C_S - C_f),$$

from which

$$C_f = \frac{A_B K_B C_i + A_S K_S C_S}{A_B K_B + A_S K_S} \quad (13)$$

It can be seen from Eq. 13 that the value of C_f must fall between C_i and C_S. From Eqs. 12 and 13 it follows that

$$\log_{10}\left[\frac{C_f - C_0}{C_f - C_L}\right] = 0.434\, t\, \frac{K_B A_B + K_S A_S}{V} \quad (14)$$

If K_S and K_B are truly constant it would follow that Eq. 14 will plot as a straight line similar to curve B in Figure 2. It does not follow, however, that the authors' Eq. 4 should plot as a straight line. From Eq. 12 it may be shown that

$$\log_{10}\left[\frac{C_i - C_0}{C_i - C_L}\right] = 0.434\, t\, \frac{K_B A_B + K_S A_S}{V} + \log_{10}\left\{1 + \frac{K_S A_S (C_S - C_L)}{K_B A_B (C_i - C_L)} - \frac{K_S A_S (C_S - C_0)}{K_B A_B (C_i - C_L)} \times 10^M\right\} \quad (15)$$

in which

$$M = -0.434\, t\, \frac{K_B A_B + K_S A_S}{V}.$$

If K_S were zero, the value of the last term in Eq. 15 would be zero and Eq. 15 would reduce to Eq. 14. For any given value of K_S the value of the last term is zero at time, $t = 0$, and takes on negative values of increasing magnitude as t increases. This could account for the shape of curve B in Figure 2.

The coefficient, K, as used in this paper, is an over-all coefficient, but is based on the bubble area alone. Then from Eqs. 3 and 11 it is evident that

$$\frac{dc}{dt} = \frac{KA_B}{V}(C_i - C_L) = \frac{K_B A_B}{V}(C_i - C_L) + \frac{K_S A_S}{V}(C_S - C_L),$$

from which it follows that:

$$K = K_B + \frac{K_S A_S}{A_B}\frac{(C_S - C_L)}{(C_i - C_L)} \quad (16)$$

Since the value of $\frac{C_S - C_L}{C_i - C_L}$ gradually

decreases with time, it is evident that K must do the same.

It is evident that the contribution of the oxygen transfer across the surface to the total aeration depends upon the relative magnitudes of $K_S A_S$ and $K_B A_B$. For shallow tanks it will be relatively large and it decreases with increasing depth of tank. Eq. 16 helps to explain the decrease in K with depth as shown in Figure 5, and Eq. 13 is in accordance with the trends shown in Figure 7.

It cannot be assumed that the value of K_S for the surface area is the same as K_B for the bubble surface, or even that K_S is constant for the entire surface area. The authors have concluded that the effective value of the coefficient for the surface area in their experiments is higher than for the bubbles because the liquid layer containing dissolved oxygen at a relatively high concentration is left behind by each escaping bubble and also because the agitation of the surface enhances the transfer of oxygen from the atmosphere. In these experiments the air bubbles were distributed over the entire horizontal area. However, in most air diffusion tanks the bubble column covers a relatively small portion of the floor area. It is to be expected then, that the effective value of K_S for that portion of the surface area through which the bubbles are escaping may be higher than K_B, but that the value for the remainder of the surface area may be considerably lower. Evidence that this is the case was provided by experimental work done in England by Holroyd and Parker.* In their experiments they worked with a constant volume and height of water and with a small air diffuser which produced a bubble column covering about 11 per cent of the horizontal area of the container. They measured the over-all transfer coefficients obtained for the system with the diffuser set at different depths below the water surface. This over-all coefficient is simply the slope of the logarithmic curve (Eq. 14) multiplied by 2.303. When they plotted the values obtained for the over-all coefficient against the depth of the diffuser below the surface, the points fell on a straight line which could be extrapolated back to a substantial value at zero depth of diffuser. Other experiments showed that the over-all coefficients were diminished when portions of the surface area were covered with a layer of paraffin. The results implied that a considerable percentage of the oxygen transfer was taking place through the surface area. Holroyd and Parker calculated the values of K for their particular set-up, as follows: 178 cm. per hr. for the bubble area, 264 cm. per hr. for that portion of the surface area from which the bubbles were escaping, and an average of only 24 cm. per hr. for the rest of the surface area. Their calculations indicated a value of K_S at the surface varying from a maximum value centered over the bubble column to as low as 6 cm. per hr. at the periphery of the container.

In conclusion, it would appear that the transfer of oxygen across the surface area of the tank is an important factor for diffused air aeration and that the values of K_B and K_S should be evaluated separately in basic studies of the process. It would be of considerable interest if the authors could compute the separate values from their data.

* Holroyd, A., and Parker, H. B., "Investigations on the Dynamics of Aeration." *Jour. Inst. Sew. Purif.*, Part 3, p. 292 (1949).

SERVICE CHARGES FOR INDUSTRIAL WASTES TREATMENT *

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Treatment of a relatively large volume of industrial waste or a particularly strong industrial waste in a municipal plant often makes equitable distribution of costs difficult. Sewage disposal has been associated with public health and general welfare for so long that in most communities it is still considered a public charge to be borne by the community as a whole. Special assessments and taxes have been levied on benefiting property owners for sewer extensions, but the cost of trunk sewers, interceptors, and sewage treatment plants has generally been charged to the entire area served.

As long as sewage works were financed by general obligation bonds and operating costs were paid from general revenues of the municipalities, there was little reason to question the allocation of costs among the various users. The increased costs of all municipal services and the growing popularity of revenue bonds for financing new sewage works have focused attention on service charges and other methods of assessing waste disposal costs.

In any community of heterogeneous residences, commercial establishments, and industries, the financing of sewage works entirely by *ad valorem* taxes on real estate cannot be equitable. The relation between the value of sewage service and the assessed valuation of the real estate is far from constant.

At first thought, it would seem that charges based entirely on the quantity of sewage discharged into the system would be most equitable. However, if the full costs of sewage service are assessed entirely on the quantity of sewage, the property owners who do not use the sewer system or who use it only to a limited extent do not pay anything for the substantial indirect benefits they derive. Sewage works benefit all classes of property owners and inhabitants in the form of increased value of property, improved public health in the community etc. The same reasoning applies to an industry in the community, even if it has no liquid waste, or if it provides its own waste treatment. Conversely, the industry with a strong liquid waste difficult to treat is subsidized by the community if the industrial waste is accepted as ordinary sewage without any surcharge.

Recognition that the value of sewage service is not equal for all users and landowners and that the value of service is usually not proportional to the assessed valuation of the property has lead to various schemes in addition to *ad valorem* taxes for allocating sewage works costs. These include one or more of the following:

1. Charges based on the number of plumbing fixtures.
2. Assessments based on the lot frontage.
3. Service charges, usually a function of the water bill. (Frequently such charges are levied to cover operating expenses only, and the capital costs are paid from *ad valorem* taxes or from general revenues of the city.

* Presented at 1953 Annual Meeting, West Virginia Sewage and Industrial Wastes Assn.; Morgantown, W. Va.; Sept. 2–3, 1953.

In many places a service charge of 50 or 100 per cent of the water bill, for example, has been adopted as "reasonable." As much revenue as possible is raised in this manner, and any deficit is raised by general taxation.)

4. Service charges based not only on the quantity, but also on the strength of waste.

In general, the first three apply to domestic and commercial sewage service, and the fourth to the disposal of industrial wastes in the municipal sewer system. This discussion is directed primarily to the industrial waste aspects.

In most communities the wastes from small industrial plants and commercial establishments (such as laundries, restaurants, and car washers) are accepted into the sewer system without question or special charge. If a waste is excessively strong or perhaps harmful to the sewers or treatment process, the waste may be excluded from the sewer system by ordinance. Otherwise, it is ordinarily not worth while to distinguish these users from domestic users. This is especially so in built-up, congested parts of a city or town, where the wastes have always been disposed of through the public sewers, and where there is no other practical solution. Politically, it is difficult to levy special charges on small establishments because the public recognizes that these establishments carry a considerable tax burden in support of schools, hospitals, parks, etc., from which they derive no direct benefit. In one city, even though waste from small copper and brass mills necessitated raw sludge incineration in place of digestion, the laundry and small plant owners successfully opposed the establishment of a service charge based on water consumption for financing the operation of a new sewage treatment plant. The wastes from the large mills, which carry a large part of the general tax burden, were not involved because these wastes do not discharge into the sewer system in any event.

In another city, where one textile plant accounts for only a small part of the total flow but nearly two thirds of the chlorination costs, no special charge is assessed. The people involved recognize the inequities, but the importance of the industry to the community, the taxes it pays, etc., are accepted as justification for the present procedure. Many other similar instances could be cited. They are proof that this problem often cannot be solved by simple arithmetic alone.

Most service charges paid by industries are based first on the quantity of flow. This is determined from the water consumption or by metering the waste as it enters the public sewer system. Ordinances usually stipulate that a suitable water meter or waste meter be installed if city water is not used and that a meter may be installed to measure the actual quantity of waste if a substantial part of the water consumed in the plant does not reach the sewer. Some cities require continuous measurement of the waste flow. In others the flow is not spot-checked from time to time and an average value agreed upon. In at least one instance the average waste flow has been related to the output of the plant, and the monthly statement of production is accepted. Weirs, orifices, or nozzles can be placed easily in new installations. It is more difficult in old installations, particularly where the available head is limited; therefore, approximate data sometimes must be accepted. At Charlotte, N. C., where a new ordinance is being put into effect, the authorities hope to require a standard installation in order that a single portable automatic sampler and instrument can be shifted from one plant to another.

The second factor to be considered in fixing industrial waste charges is, of course, the strength of the sewage and the relative cost of treating it. If

a surcharge is applied to industrial wastes, it is usually based on the difference in the strength of the industrial waste and the average sewage for the community. Various standards have been adopted, but in general they include consideration of suspended solids, B.O.D., and chlorine demand. The suspended solids load is important in allocating the cost of primary treatment and sludge disposal. The B.O.D. is usually important only if secondary treatment is provided; in this case, the B.O.D. load is reflected in plant investment, operating costs, or both. The chlorine demand of the waste influences not only the capacity of equipment to be installed, but also, even more directly, the cost of chlorine to be applied, and is important wherever disinfection is included. In a rather unusual situation, the engineers for the Middlesex County, (N. J.) Sewerage Authority proposed charging a substantial part of the trunk sewer costs to B.O.D. loading. This was done because the high B.O.D. of the wastes in conjunction with the small flows of the Raritan River indicated the need for a large primary plant on Newark Bay instead of smaller complete treatment plants upstream. Delays, both technical and political, have necessitated some changes in the original plan.

One objection to special charges for industrial wastes of varying strengths is the difficulty of regularly obtaining accurate samples and analyses. Few municipal departments have either the personnel or the funds to do the work frequently. In many places representative samples were taken some years ago and contracts fixed accordingly. In others, grab samples are taken from time to time. Practice varies so widely that no worth-while summary is possible. However, illustrative examples are noted in Table I.

Regular sampling is desirable, but occasional spot sampling is not to be

TABLE I.—Examples of Municipal Sampling Procedures for Determining Sewage Service Charges

Location[1]	Characteristics Considered				Sampling Frequency	Comments
	S.S.	B.O.D.	Cl_2	Other		
Anaheim, Calif.[2,3]		×			Monthly, with extra at start of (canning) season.	Heavy chlorination required pending repair of outfall.
Belleville, Ill.		×			Grab samples to check surveys; surveys consist of 7-day, 24-hr. composites.	
Buffalo, N. Y.[4]	×		×		Contracts established at start of program on basis of two 14-day tests.	Insufficient personnel for regular checkup.
Charlotte, N. C.[5]		×			Every 3 months; automatic sampler in standard installation.[6]	
Ft. Dodge, Iowa		×			Industries classified by ordinance in B.O.D. grades; exact B.O.D. unimportant.	
Fullerton, Calif.[4]		×	×		Weekly.	Industries required to chlorinate strong wastes.
Lansing, Mich.[2]	×	×	×	Tot. sol. and pH	Grab samples weekly or bi-weekly.	Charge not yet established.
New Brunswick, N.J.[3]	×		×		Ordinance specifies semiannually, or quarterly if necessary.	
Phoenix, Ariz.[2,7]	×	×			Monthly, composite.	
Winchester, Va.		×			For 4 yr., quarterly composite samples; now, spot checks on several days each quarter.	

[1] All use water consumption for estimating waste flows.
[2] Waste meters also used in some instances.
[3] Flow gaged monthly.
[4] Some wastes estimated, one related to production.
[5] Proposed.
[6] No charge unless flow exceeds 72,000 g.p.d.
[7] Flow gaged continuously.

condemned in all instances. Some industrial wastes are remarkably uniform, and variations from the normal may have no great significance. The important thing to keep in mind, however, is that where samples are taken at long intervals and necessarily yield only approximate data, there is no sense in setting up complex mathematical formulas accounting for relatively minor factors. Most schedules have been realistic in this respect.

Probably the most thorough and logical approach to the problem to date is presented in a report (1) prepared by a Joint Committee of the A.S.C.E. and the Section of Municipal Law of the American Bar Assn. The full report must be read carefully for appreciation of the reasoning and of the calculations involved. Schroepfer (2) has applied the Joint Committee's recommendations to an illustrative example.

The recommendations of the Joint Committee are based on the following statement of the fundamental principle:

"The needed total annual revenue of a water or sewage works shall be contributed by users and non-users (or by users and properties) for whose use, need, and benefit the facilities of the works are provided approximately in proportion to the cost of providing the use and the benefits of the works."

In applying this principle the capital costs are allocated between property and users in proportion to the relative shares of the capacity provided for each. The operating and maintenance costs are similarly allocated between property and users in proportion to their shares of these costs. Thus, in a combined sewer system with an interceptor and sewage treatment plant, a large part of the interceptor cost would be charged to property (for storm water, infiltration, public use, and reserve for future use); the balance would be charged to domestic and industrial users. Most of the treatment plant costs would be charged to the users, but property would carry a proportionate share of the cost of capacity made necessary because of storm flows, infiltration, allowance for future use, etc. Finally, the cost to the users would be allocated among the users in proportion to the volume of waste, the suspended solids, and the B.O.D. (or chlorine demand, in some cases).

The Joint Committee procedure is logical, but not simple to apply. Considerable judgment is needed to distribute the costs fairly. It is recognized that adjustments cannot be made for minor differences in sewage strength, nor can the relative weights assigned to property and users be adjusted often or whenever there is a change in conditions. Usually it will not pay to set up special charges for industries whose wastes do not contain at least 50 per cent more suspended solids or B.O.D. than average sewage.

It is easier to allocate operating costs than fixed charges. The increased quantity of sludge contributed by an industry, the increased air requirements, or the chlorine required for disinfection can be determined reasonably well. The allocation of fixed charges is more difficult because fixed charges necessarily are applied over a long period of years, and the industrial waste load may change rapidly. At Topeka, Kans., a meat packing plant contributed more than one-half of the B.O.D. load to an activated sludge plant. The meat packing plant moved away, and the B.O.D. dropped accordingly. However, the capacity of the sewage treatment works was limited principally by the final tanks, and even with the packinghouse waste eliminated the sewage treatment works could handle no more sewage than previously. Situations like this pose nice problems in cost allocation.

Not many communities are likely to carry out the Joint Committee's procedure in all detail. In some states changes in municipal finance laws would be needed. However, the basic

principles as outlined by the Joint Committee provide an excellent starting point, and the procedure can be simplified to suit particular situations. It is better to accept approximations of a rational method than to follow an arbitrary but simple procedure that is obviously unfair.

Some of the difficulties in arriving at equitable arrangements between municipalities and industries are due to differences in the service provided and in the attitude of the people involved. Included are the following:

1. Municipal sewage works normally provide a relatively small amount of service to many people. There may be substantial inequities in cost allocation, but even if one person pays more than he should, his total cost for sewage service is such a small part of his normal budget that the discrepancy does not cause concern. Normal variations in other public services (such as street maintenance, school bus routes, etc.) are likely to be much more important. In contrast, an industrial waste may account for a substantial part of the total load in the municipal sewage treatment plant and for much of the revenue; discrepancies here are relatively much more important.

2. Even in fast-growing communities, the future sewage disposal needs can be estimated within reasonable limits for a good many years into the future. Industrial waste treatment requirements may double overnight or may vanish entirely if the product is changed or if the industry moves away. The uncertainty of future industrial needs makes it almost imperative that the municipality insist upon either a substantial initial contribution towards capital costs by the industry or a guaranteed minimum revenue for a period of years.

3. The financing of municipal sewage works usually involves the sale of bonds, frequently preceded by a popular referendum. It is obviously not practical to come back to the people every few years with a request for funds to build additions to treatment facilities. Therefore, the people who are charged with the planning of such works necessarily provide excess capacity to take care of anticipated loads. Industries do not have to do this. Industries can build treatment plants adequate for their present needs with the expectation that the facilities can be expanded when, as, and if the mill is enlarged. Presumably the increased revenues from greater production will pay for the waste treatment when it is needed.

4. Most industrialists feel that municipal sewage treatment plants cost more than they should and that money has been wasted to make them "show places." Some of this criticism is justified. However, there are two points that should be brought out. The first is the tendency of industrialists to over-simplify what they will have to do in the way of treatment and to underestimate their over-all costs. Industries do save some money by using wood or steel tanks and equipment less durable than a municipality would demand to assure good service at least for the life of the bonds, say 25 or 30 years. Industries are able to gamble on possible equipment failures, overloading of plants, etc., and standby capacity is rarely provided, but the costs of the basic structures and equipment are substantially the same whether built for industries or municipalities. Industrialists frequently think in terms of out-of-pocket expense for labor and materials, with no charges for engineering, overhead, contractor's profit, etc.

In the second place, experience has shown that a reasonably attractive municipal treatment plant with a few labor-saving conveniences pays off in the long run in getting competent personnel and good operation. There is no reason for elaborate ornamentation, excessive instrumentation, or completely automatic control, but good

working conditions and equipment should be provided.

As a general rule, industrial wastes that are not unusually strong, toxic, or corrosive can be disposed of at less cost through a municipal plant than by means of a separate industrial waste plant. Frequently, dilution with normal domestic sewage makes an industrial waste much easier to treat. Occasionally, wastes from two or more plants tend to neutralize each other. Combining the wastes in a single treatment plant is likely to save money for all concerned. It is also safe to say that, in general, municipal operations will yield more regular and better results. One cannot escape the fact that industrial waste treatment is a necessary evil and nuisance to industrialists, and it tends to become the orphan boy. Sewage and waste treatment is usually the fulltime job of one or many persons in a municipal system.

The problem of cost allocation in each case requires careful study, but an equitable solution is nearly always possible. Therefore, except where the industrial wastes are unusually severe in strength or volume, or where the industrial plants are a long distance from the public sewer system, the benefits of joint treatment should be explored thoroughly.

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PROGRESS REPORT ON AIR DISPERSION STUDY

Under a grant from the National Institutes of Health, A. T. Ippen and C. E. Carver, Jr., of Massachusetts Institute of Technology, are carrying out fundamental research on methods of air dispersion. Begun in October 1948, the study is aimed at securing greater efficiency in solution of oxygen from air supplied in the activated sludge process.

The initial phase of the program involved development of instrumentation for continuous dissolved oxygen measurement. In the second phase, a series of controlled experiments was run using both air and oxygen in bubble sizes ranging from 1.25 to 2.50 mm. in diameter in water containing various oxygen concentrations. Results of this phase have been reported elsewhere in THIS JOURNAL (see page 813).

The third phase concerned extension of the bubble sizes to even smaller than previously employed. With bubbles of 0.26- to 1.0-mm. diameter tests were run at a 140-in. depth of liquid, both with and without a synthetic detergent in various concentrations to determine the effect on the rate of oxygen absorption. Analysis of these latter experiments is not yet completed.

Further research is proposed to obtain quantitative data as to the degree of turbulent mixing available from passage of freely rising bubbles through a liquid. Size-frequency distribution of sediment will be used to ascertain the magnitude of a mixing coefficient reflective of the turbulence engendered by the bubbles.

HYDRAULIC BEHAVIOR OF STORM-WATER INLETS

III. Flow into Deflector Inlets

By Wen-Hsiung Li, Bertram C. Goodell, and John C. Geyer

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Methods for calculating the capacities of undepressed grate inlets and both undepressed and depressed curb inlets were presented, respectively, in the first and second articles of this series (1) (2). This third article deals with curb inlets in front of which diagonal slots are cast into the gutter. The ridges between the slots are called deflectors and thus the name "deflector inlet" has been adopted to describe the whole arrangement. Figure 1 shows the type of deflector inlet to which the analyses in this paper specifically apply. The deflectors increase the inlet capacity by creating a standing wave beside the curb opening; therefore, deflectors of shapes other than those studied would probably work as well if they provided an equally rough surface at the inlet. In order to estimate the capacity of inlets with non-rectangular deflectors, engineering judgment can be used to sketch a series of rectangular notches and ridges believed to have a roughness about equivalent to that of the non-rectangular deflectors.

Deflector inlets are of practical interest because when they are installed in steep streets, their intake capacity is greater than that of most other types of inlets. Furthermore, since the top of the deflectors are level with the pavement, this type of inlet is less annoying to traffic than a depressed inlet.

The tests reported here were conducted with inlet models of 1:3 scale (1). Inlets of different dimensions and streets at different grades were tested. In each case, the inlet capacities were measured for different quantities of gutter flow up to flows which gave 30 per cent carry-over. Dimensional analysis is employed to account for all of the physical variables that affect the inlet capacity.

Letter Symbols

The following symbols are used in this article (see Figure 1):

- a = depth of slots at curb line (ft.)
- b = width of deflector (ft.)
- c = clearance between deflectors, or width of slots (ft.)
- g = gravitational force per unit mass (gravitational acceleration) (ft. per sec. per sec.)
- L = length of curb opening (ft.)
- N = $(L \sin \alpha - c)/(b + c)$ = number of slots.
- n = Manning's roughness coefficient for gutter.
- Q_0 = quantity of gutter flow (c.f.s.)
- Q = discharge into inlet (c.f.s.)
- s = street grade (ft. per ft.)
- v_0 = mean velocity of gutter flow (ft. per sec.)
- W = width of deflector area (ft.)
- y_0 = depth of gutter flow at curb (ft.)
- α = angle between deflectors and curb-line.
- θ_0 = angle between cross-section of street and vertical.

Other symbols used are defined where they first appear.

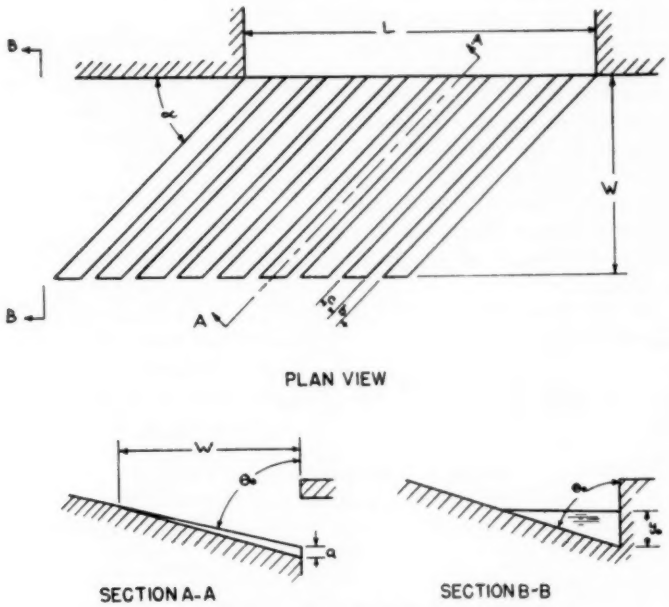

FIGURE 1.—Deflector inlet design.

Analysis of Test Data

The discharge, Q, into the deflector inlet shown in Figure 1 depends upon the length of the curb opening, L; the width of the deflectors, b; the depth of the slots at the curb, a; the clearance between deflectors, c; the width of the deflector area, W; the angle between the deflectors and the curb, α; the gravity acceleration, g; the street crown slope as measured by the angle, θ_0; the flow depth, y_0; and the velocity of the approaching flow, v_0. The slope and roughness of the gutter and the gutter flow, Q_0, are accounted for in the values of v_0, y_0, and θ_0.

Since these eleven quantities can be expressed in terms of two fundamental physical dimensions—namely, length and time—there can only be nine independent dimensionless quantities, say,

$$\frac{Q}{L\,y_0\sqrt{g\,y_0}},\ \theta_0,\ \alpha,\ \frac{W}{L},\ \frac{a}{L},\ \frac{c}{b},\ \frac{L\sin\alpha}{b+c},\ \frac{v_0}{\sqrt{g\,y_0}},\ \text{and}\ \frac{2Q}{v_0\,y_0^2\tan\theta_0}.$$

Inasmuch as the gutter flow $Q_0 = v_0\,y_0^2 \tan\theta_0/2$; the number of notches between the deflectors, $N \cong L\,(\sin\alpha)/(b+c)$, and $\frac{v_0}{\sqrt{g\,y_0}} \cong 0.14\,\frac{\sqrt{s}}{n}$ as shown in Part I (1); the nine dimensionless quantities may be set into the following functional relationship:

$$\frac{Q}{L\,y_0\sqrt{g\,y_0}} = \phi\left(\theta_0, \alpha, \frac{W}{L}, \frac{a}{L}, \frac{c}{b}, N, \frac{\sqrt{s}}{n}, \frac{Q}{Q_0}\right).$$

In the model tests the values of W/L used ranged from 1/3 to 1, of a/L from 1/25 to 1/50, of $\sqrt{s}/n$ from 12 to 22, and of Q/Q_0 from 0.7 to 1. The value of c/b was fixed at 2 and at 5, and the value of N at 6, 9, and 12. To reduce the amount of experimental work, only cases with $\tan\theta_0 = 18$, and $\alpha = 45°$ were thoroughly investigated. In view of the fact that the value of $\frac{Q}{L\,y_0\sqrt{g\,y_0}}$ for undepressed curb inlets is practically

independent of the street crown (2), only a few tests with other values of $\tan \theta_0$ were made. The chosen value of 18 for $\tan \theta_0$ is believed to be representative of the average conditions in streets. The deflector angle of 45° was chosen for thorough investigation because preliminary tests indicated that this value was about as effective as any in which the deflectors were parallel with one another.

From the test data with $\alpha = 45°$, it is found that for a given inlet

$$\frac{Q}{L\, y_0 \sqrt{g\, y_0}} = 0.058 \left(\frac{c}{b}\right)^{1/20} \frac{\sqrt{s}}{n} \sqrt{\frac{W}{L}} \quad . \quad (1)$$

The value of $\dfrac{Q}{L\, y_0 \sqrt{g\, y_0}}$ changes only slightly with change in the value of c/b. For example, this quantity increases only 5 per cent when c/b is increased from 2 to 5.

For $c/b = 2$, Eq. 1 may be written:

$$Q = 0.06\, y_0 \sqrt{g\, y_0\, L\, W}\, \frac{\sqrt{s}}{n} \quad . \quad . \quad . \quad . \quad (2)$$

Test data for an inlet with this deflector geometry are shown in Table I. Figure 2 has been prepared to show graphically the performance of the inlet.

As indicated by Eq. 1, the inlet ca-

TABLE I.—Test Data for Deflector Inlet

(L = 6 ft. 3in.; W = 2 ft. 3 in.; c = 4 in.; b = 2 in.)

Street Grade (s)	Calibrated $\frac{\sqrt{s}}{n}$	Q_0 (c.f.s.)	Q (c.f.s.)	$\frac{Q}{Q_0}$	Computed y_0 (ft.)	$\frac{Q}{L y_0 \sqrt{g y_0}}$
0.02	13.6	3.88	2.52	0.65	0.284	0.48
		3.50	2.42	0.69	0.273	0.48
		2.87	2.23	0.78	0.254	0.50
		2.51	2.09	0.83	0.242	0.50
		1.99	1.82	0.92	0.221	0.50
		1.57	1.54	0.98	0.203	0.48
						0.49[1]
0.03	15.5	4.00	2.74	0.69	0.274	0.54
		3.64	2.56	0.71	0.265	0.53
		3.40	2.50	0.74	0.258	0.54
		3.08	2.40	0.78	0.248	0.54
		2.12	2.08	0.94	0.217	0.58
		1.68	1.67	0.99	0.198	0.54
						0.54[1]
0.04	16.8	4.08	3.06	0.75	0.268	0.63
		3.51	2.60	0.74	0.254	0.60
		3.51	2.73	0.78	0.254	0.57
		3.21	2.78	0.86	0.244	0.65
		2.46	2.28	0.92	0.220	0.62
		2.14	2.08	0.97	0.211	0.60
						0.61[1]
0.05	17.9	4.16	3.01	0.73	0.262	0.64
		3.56	2.81	0.79	0.248	0.64
		2.72	2.54	0.93	0.223	0.67
		2.17	2.08	0.96	0.207	0.62
		2.09	2.04	0.98	0.203	0.63
						0.64[1]

TABLE I.—*Continued*

Street Grade (s)	Calibrated $\frac{\sqrt{s}}{n}$	Q_0 (c.f.s.)	Q (c.f.s.)	$\frac{Q}{Q_0}$	Computed $\frac{y_0}{}$ (ft.)	$\frac{Q}{L_{y_0}\sqrt{g y_0}}$
0.06	18.9	4.44	3.22	0.73	0.265	0.67
		3.73	3.01	0.81	0.247	0.70
		3.32	2.82	0.85	0.236	0.70
		3.00	2.75	0.92	0.228	0.72
		2.56	2.43	0.95	0.215	0.65
		2.25	2.20	0.98	0.205	0.67
						0.68[1]
0.07	19.9	4.25	3.32	0.78	0.255	0.72
		3.94	3.21	0.82	0.248	0.73
		3.23	2.93	0.91	0.230	0.75
		2.93	2.78	0.95	0.222	0.76
		2.68	2.64	0.98	0.215	0.74
		2.31	2.28	0.99	0.203	0.70
						0.73[1]
0.08	20.6	4.87	3.61	0.74	0.266	0.70
		4.52	3.48	0.77	0.258	0.74
		4.15	3.33	0.80	0.249	0.75
		3.74	3.23	0.86	0.239	0.78
		3.15	3.05	0.97	0.226	0.80
		2.69	2.67	0.99	0.212	0.77
						0.76[1]
0.09	21.3	5.37	3.84	0.72	0.272	0.76
		4.84	3.74	0.77	0.261	0.78
		3.90	3.44	0.86	0.242	0.82
		3.31	3.17	0.96	0.227	0.82
		2.98	2.93	0.98	0.217	0.81
						0.80[1]

[1] Average.

pacity per unit length, Q/L, under a given gutter flow is independent of a/L when $a/L > 1/50$, and of N when $N > 6$, and is practically independent of c/b. This may be explained as follows: The outer portion of the gutter flow striking the deflectors is directed towards the curb opening. This flow from the outer portion of the gutter blocks the flow coming to the inlet near the curb, and creates a phenomenon similar to the swell over obstacles in a supercritical flow. Gutter flow is invariably supercritical if the grade is about 0.01 or greater. The increased depth of flow in front of the curb opening accounts for the higher inlet capacity. The magnitude of this increase in depth is independent of the precise number and the geometrical details of the deflectors so long as a few deflectors are present. Thus, in designing an inlet of this type, a small value of the depth, a, say $L/50$, may be used (for example, $a = 1\frac{1}{4}$ in. for a 5-ft. opening).

Full-scale models with values of the slot width, c, equal to 2, 4, and 7 in. for a deflector width, b, of 2 in. and slot depth, a, of 2 in. were used to determine the effect of the deflector inlet on moving traffic. In passing over the 2-in. and 4-in. slots no perceptible vibration

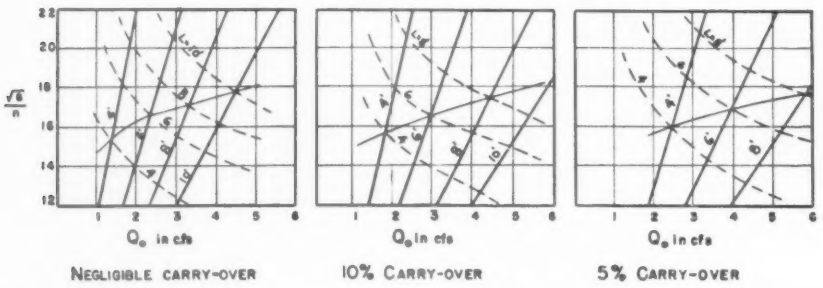

FIGURE 2.—Required lengths of curb inlets in streets with crown slope of $\frac{3}{4}$ in. per foot. Dashed lines are for curb inlets in 3-in. depression, solid lines for deflector inlets with $W = 2.4$ ft.

was transmitted to the occupants of an automobile. On the other hand, considerable vibration was felt when driving across the inlet with 7 in. slots. The extent to which slots of various width tend to become clogged with road dust or other material will have to be determined by field experience. With a slot 4 or 5 in. wide it seems reasonable to expect that both moving traffic and moving water will keep the slots sufficiently clear to function properly.

According to Eq. 1, the inlet capacity increases as the square root of the width, W, of the deflector area. The value of W selected when designing an inlet depends on (*a*) the width of the flow in the gutter at capacity, (b) economic

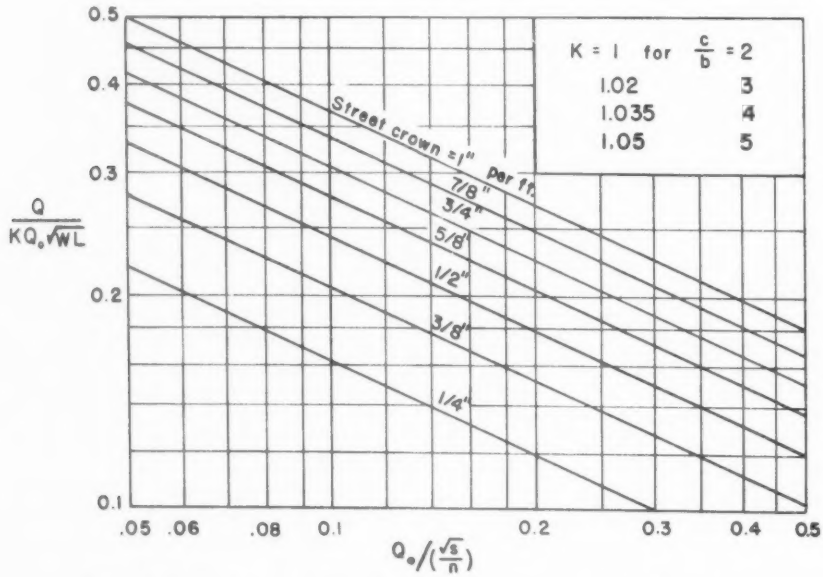

FIGURE 3.—Design curves for deflector inlets. Curves apply to cases where $W/L \geq 1/3$, $a/L \geq 1/50$, $22 \geq \sqrt{s}/n \geq 12$, $Q/Q_o \geq 0.7$, and $N \geq 6$.

considerations, and (c) the distance beyond which the designer may consider it undesirable to extend the slots.

Design Curves

Manning's formula for open-channel flow was used to prepare the design curves shown in Figure 3. As previously demonstrated (1), Manning's formula gives

$$y_0 = 1.326 \frac{(1 + \sec \theta_0)^{1/4}}{(\tan \theta_0)^{5/8}} \left(\frac{Q_0}{\sqrt{s}/n}\right)^{3/8}$$

for gutters of uniform cross-slope as defined by the angle θ_0. Substituting this expression into Eq. 1 gives

$$\frac{Q}{Q_0\sqrt{WL}} = \left[0.504 \left(\frac{c}{b}\right)^{1/20} \frac{(1+\sec \theta_0)^{3/8}}{(\tan \theta_0)^{15/16}}\right] \times \left(\frac{\sqrt{s}/n}{Q_0}\right)^{7/16} \quad \ldots . (3)$$

Figure 3 has been prepared to facilitate the solution of this equation for values of c/b ranging from 2 to 5.

Example 1.—Given gutter flow Q_0 = 6 c.f.s., street grade s = 6 per cent, street crown = $\frac{3}{4}$ in. per ft., and n = 0.013. The width, W, is to be kept within 3 ft., and the slot width, c, is to be less than 4.5 in. Design a curb inlet with deflectors to capture 90 per cent of the gutter flow.

Here $\sqrt{s}/n = \sqrt{0.06}/0.013 = 18.9$, which is within the limits of application (12 to 22) of Eq. 1 and Figure 3. Use $c/b = 2$. With $Q_0/(\sqrt{s}/n) = 6/18.9 = 0.318$, and street crown = $\frac{3}{4}$ in. per ft., $\frac{Q}{Q_0\sqrt{WL}} = 0.185$ from Figure 3. Since the specified $Q/Q_0 = 0.9$, the required $\sqrt{WL} = 0.9/0.185 = 4.86$, or the required $WL = 23.6$. Using the maximum allowable W = 3 ft., the required $L = 23.6/3 = 7.9$ ft. Use L = 8 ft. (Check: $W/L = 3/8 > 1/3$, O.K.) Use a depth of slot at the curb, $a = L/50$, of say 2 in. Use 10 (>6) deflectors with width b = 2 in. spaced with clearance c = 4 in.

Example 2.—Find the flow into a 6-ft. curb inlet with deflectors, given Q_0 = 3 c.f.s., s = 0.05, n = 0.013, W = 2 ft., c = 4.5 in., b = 1.5 in. (N = 6), a = 1.5 in., and street crown = $\frac{1}{2}$ in. per ft.

Here $W/L = 1/3$, $a/L = 0.021$, $\sqrt{s}/n = 17.2$, and N = 6. Under these conditions, Eq. 1 and Figure 3 are applicable. With $Q_0/(\sqrt{s}/n) = 3/17.2 = 0.174$, street crown = $\frac{1}{2}$ in. per ft., and $c/b = 4.5/1.5 = 3$, $\frac{Q}{1.02\,Q_0\sqrt{WL}} = 0.19$. Therefore, $Q = 0.19 \times 1.02 \times 3 \times \sqrt{2 \times 6} = 2.02$ c.f.s. (Check: $Q/Q_0 \cong 0.7$, O.K.)

Conclusion

The capacity of deflector inlets increases with the street grade, a characteristic that is the opposite of that shown by other types of inlets.

As previously indicated (2), the capacity of a curb-opening inlet without depression is given by

$$\frac{Q}{L\,y_0\sqrt{g\,y_0}} = 0.20 \text{ to } 0.23.$$

As shown by Eq. 1, the capacity of deflector inlets is much higher, and in steep streets may be several times as large as that of undepressed curb inlets. The performance of deflector inlets and depressed curb inlets is compared in Figure 2 (the dashed lines in Figure 2 are reproduced from Figure 10 in Part II of this series (2)). It can be seen that for $\sqrt{s}/n > 17$, the deflector inlet has the greater capacity. The depth of the slots in the deflector inlets is in every case smaller than the 3-in. depression depth to which the curves for depressed curb inlets apply.

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SEWER INSIDE A SEWER

Waterloo, Iowa, recently constructed a sewer within a sewer. The original line, a 12-ft. concrete arch built in 1904, had become a combined sanitary and storm sewer. The city's plan called for separation of storm and sanitary flows by constructing new lines either inside or outside of the existing lines. In one area, residential in part and in part in a business district, it was feasible to construct the new line inside the old one (Figure 1) rather than to trench down to the level of the existing sewer to install a new pipeline.

A twin, 21-in. diameter concrete pipe sewer 3,526 ft. long was installed. Standard 4-ft. lengths of reinforced concrete sewer pipe were lowered into the existing line through top openings made about every 1,000 ft.

The operation called for placing the pipe, drilling and placing anchor rods in the side walls and floor, setting the forms, and pouring the side encasement. Progress was rapid, with 125 ft. of twin line (250 ft. total) installed per day. The reduced area of the storm sewer is not of consequence because of the substantial volume of flow carried by the new sanitary sewer.

FIGURE 1.—Twin 21-in. sanitary sewer inside large storm drain saved money and inconvenience along new sewer route.

Industrial Wastes

DISPOSAL OF ELECTROPLATING WASTES BY ONEIDA, LTD.*

I. Survey of Wastes

By Charles A. Walker and Paul W. Eichenlaub

Respectively, Associate Professor, Department of Chemical Engineering, Yale University, New Haven, Conn., and Chemist, Oneida, Ltd., Oneida, N. Y.

The main plant of Oneida, Ltd., manufacturers of silver plated tableware and hollow ware, sterling tableware, stainless steel tableware, and various metal products related to the needs of the armed forces, is located in Sherrill, N. Y., in the midst of a rural area containing numerous dairy farms. The small streams of the area and nearby Oneida Lake afford opportunities for recreation for thousands of people in the form of fishing, swimming, and boating facilities. The choice of such an area for the location of an industrial plant makes it necessary that the plant management assume the responsibility for avoiding contamination of waterways which are an important asset to the people. Such a responsibility is difficult to discharge in the case of a plating plant, as the manufacture of silver plate involves the use of a base metal containing copper and zinc and of a plating solution containing cyanides, all of which are recognized as being highly toxic to fish and other forms of aquatic life. The very thorough cleaning operations which precede the plating step and the washing of plated merchandise result unavoidably in the production of large quantities of contaminated water containing cleaners, heavy metals, and cyanides. This water must be treated chemically before it can be discharged into surrounding waterways.

Early Treatment Facilities

In 1941 a study of waste disposal at the Sherrill plant indicated the desirability of separating certain concentrated wastes from the plant effluent, all of which was routed to a nearby creek. The uncertainty of the times made it necessary, however, that disposal of these more concentrated wastes be carried out by lagooning, depending on evaporation and seepage to limit the lagoon volume and area required. There was accordingly developed at that time a thorough system of waste segregation according to types and a system of disposal lagoons.

A simplified sketch of the waste disposal system as it existed in 1951 is shown in Figure 1. Clean wastes were routed directly to the factory ditch, from which they flowed through a retention pond (designed to equalize slugs of contaminants which entered this stream by mistake) into Seonondoa Creek. Sanitary wastes were routed to a sewage treatment plant, the effluent from which entered the factory ditch. Acid wastes and alkali wastes were routed directly to lagoons, as was the

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effluent from a small unit for recovering silver from certain wastes by exchange with zinc.

At the time the system of disposal lagoons was installed it was realized that only a temporary solution to the waste disposal problem had been achieved. In 1951 it was decided by the company management that a permanent and complete solution to the waste disposal problem would be sought as rapidly as possible. A somewhat detailed account of the development which occurred in the period 1951–1953 is presented in this series of papers.

The cleaning and plating operations in the Sherrill plant are carried out in more than 130 still rinse tanks and electroplating baths and more than 110 running rinse baths. The development of waste disposal facilities in this plant began in 1941 with the installation of a waste collection system which served to segregate the liquid wastes into the following classes:

1. Clean wastes.
2. Contaminated wastes.
   (a) Silver-bearing wastes.
   (b) Acid wastes.
   (c) Alkali wastes.

The clean wastes, largely running rinses from tanks so located with respect to other tanks containing toxic materials that the probability of acci-

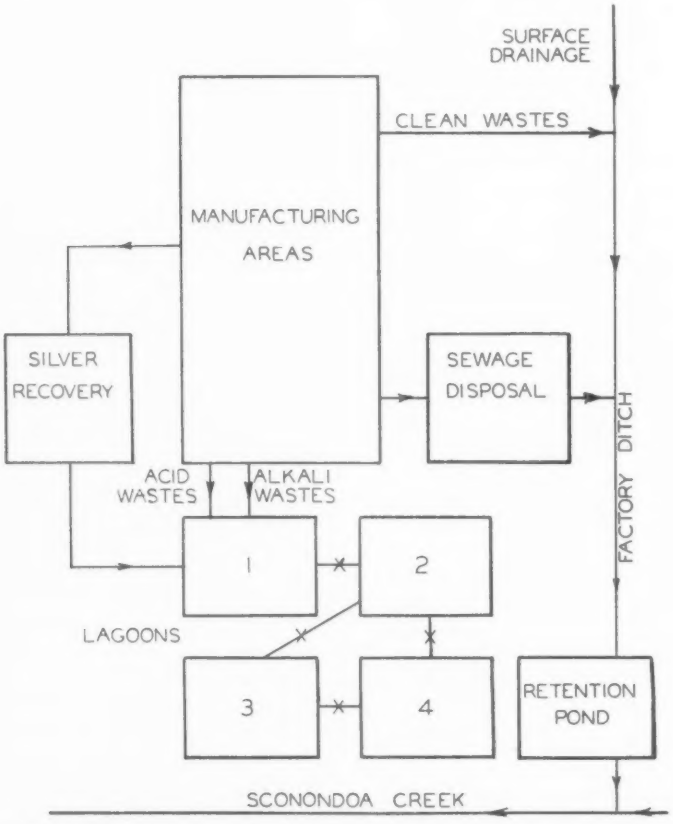

FIGURE 1.—Flow diagram of waste disposal system at Oneida, Ltd., plant in 1951.

dental contamination was very low, were routed to a ditch which discharges into Seonondoa Creek. The contaminated wastes were divided into three classes as indicated.

Dilute silver-bearing cyanide wastes were collected in large tanks and contacted with metallic zinc for the recovery of silver. The supernatant zinc cyanide solution from these tanks was drained to disposal lagoons, which also received the acid wastes and the alkali wastes. Thus the system resulted in adequate segregation of potentially harmful wastes, although it was recognized as an incomplete solution to the problem since lagooning cannot be continued indefinitely. However, this system did serve to prevent contamination of the nearby surface waters from 1941 to 1953. Furthermore, the segregation system with only a few slight modifications was found to be satisfactorily planned as regards the separation of wastes into types suitable for treatment.

Review of Segregation System

When it was decided in 1951 to proceed as rapidly as possible with the development of complete waste disposal facilities, it was necessary first to review the segregation system to insure that it was satisfactory as regards the separation into clean wastes and contaminated wastes and as regards the further separation of contaminated wastes into types suitable for treatment. It was further necessary to determine the flow rates and compositions of those wastes which required treatment.

The waste collection system was checked first to make certain that all wastes which might occasionally contain prohibitively high concentrations of toxic materials were routed to the lagoons. Furthermore, it was realized that some tanks which did not normally contain toxic materials would have to be routed to the lagoons because their proximity to other tanks containing toxic materials might tempt a workman to dispose of toxic materials through the wrong line.

TABLE I.—Analysis of Factory Ditch Water before Survey

Date	Free Cyanide (p.p.m.)	Copper (p.p.m.)	Zinc (p.p.m.)
Aug. 13, 1951	0.64	1.4	1.6
Aug. 14, 1951	1.04	2.0	1.8
Aug. 15, 1951	1.28	1.8	0.2
Aug. 16, 1951	0.48	1.2	1.6

The normal condition of the factory ditch water at the time this survey was initiated is indicated by the analyses (Table I) of water taken from the inlet of this ditch. It may be noted that the dilution of factory ditch water as it enters Seonondoa Creek may be as low as four-fold during an unusually dry season. Blending of water of the composition given in Table I with three volumes of creek water leads to concentrations of free cyanide, copper, and zinc, which are regarded as excessive by the New York State regulatory agencies. It was necessary, therefore, to attempt to locate the wastes responsible for cyanide, copper, and zinc in the factory ditch. Analytical data on a number of individual running rinses were obtained to serve as a guide in revising the segregation practice. Furthermore, it was found advisable to check the routing of wastes from every drain in the plant. This was done by the use of fluorescein as an indicator, the dye being added to each drain in turn while outfalls were observed to determine whether the discharge was routed to the ditch or to the lagoons.

TABLE II.—Analysis of Factory Ditch Water after Changes

Date	Free Cyanide (p.p.m.)	Copper (p.p.m.)	Zinc (p.p.m.)
Sept. 10, 1952	0.08	0.50	0.0
Dec. 16, 1952	0.13	0.20	0.10
Mar. 17, 1953	0.13	0.14	0.0

This program of sampling and line tracing, which required some months, revealed that small contributions to the cyanide, copper, and zinc content of the ditch water were being made by a number of dilute rinses. The net result of the program was the rerouting of about 12 discharges from the ditch line to the lagoon lines. Several hundred spot samples of the ditch water have been analyzed since these changes were made because it was deemed essential that this segregation program be perfected before a plant design was undertaken. Typical analyses of the factory ditch water as it flows into Sconondoa Creek are given in Table II. When water of this composition is diluted by a factor of at least four as it enters Sconondoa Creek, the result is a water of acceptable quality as regards the contents of cyanide and heavy metals.

The segregation system was next reviewed to determine whether the types of waste flowing from the various outfalls into the lagoons represented logical types with regard to treatment methods. It was found that the practice in the usage of waste lines involved adequate segregation of those wastes containing recoverable concentrations of silver and of those wastes containing acids and heavy metals. The so-called alkali waste, however, was found to be simply a combination of all process wastes other than those containing silver and those containing acids. Thus, there were present in the alkali wastes considerable quantities of soaps, kerosene, orthosilicates, borax, etc., as well as cyanide and heavy metals.

Investigation showed that it would be possible to separate the alkali wastes into two types by the installation of another waste line. One of these wastes would contain organic materials and some heavy metals from the cleaning operations, but no cyanide; the other would contain cyanide and heavy metals with a small amount of organic materials.

If such segregation were practiced, however, it would be necessary to install a treatment unit for each of the two types of waste. It was therefore decided that this further segregation would not be undertaken unless the development of treatment methods was made much more difficult by the complex nature of the alkali wastes. In particular, it was felt that the organic material might interfere with the oxidation of cyanides. As noted in Part II, however, it was possible to develop adequate treatment methods despite the complexity of this waste discharge. Thus the entire development of waste disposal facilities was greatly speeded by the fact that the segregation system which had been developed 12 years earlier proved adequate.

Flow Rate Determinations

An adequate waste disposal plant design requires a rather complete knowledge of flow rates of the wastes, instantaneous flow rates being of greatest importance if a continuous treatment process is to be used and average flow rates of more importance if a batch treatment process is to be used. It is frequently necessary to have a knowledge of both types of flow rates, as the variability is one factor which enters into the choice between batch and continuous processing.

Only the average flow rate of the silver-bearing wastes was measured because it was realized that the source of these wastes (largely dumpings) indicated that considerable variation in flow rates and compositions could be expected. These variations and the relatively small flow rates virtually dictated the use of a batch treatment. At the time of the survey these wastes were drained into 2,000-gal. tanks for treatment with zinc to recover silver. Operating data on this process provided adequate data on the flow rates of silver-bearing wastes.

The acid wastes originate in a bright dip unit for nickel silver and an acid

stripping unit for recovery of silver from rejects. Since continuous treatment appeared to be a definite possibility in this case, it was desired to measure instantaneous flow rates. This was accomplished by the temporary installation of water meters on the inlet lines to the two units.

The measurement of the flow rate of the alkali wastes presented the most serious problem, because this waste discharge comes from many sources. It was realized early in this work that it might be very convenient to have data on the flow rate on each of the more than 100 running rinses in the plant, not only for the purposes of the waste disposal system, but also for use in a water usage survey. The simplest method of obtaining these data appeared to be by noting the time required for each tank to fill to a certain depth and calculating the flow rate from this information and the tank dimensions. It was necessary to perform this test while the water usage in all parts of the plant was that of a typical working day in order that water line pressures be normal. Since the nature of some of the manufacturing processes made it inadvisable to drop the liquid levels in certain tanks (either by bottom drains or by siphons) during working hours, it was decided to make these measurements on a Saturday morning, when no manufacturing was in progress. All running rinses in the plant were turned on for about 4 hr. while a group of men working in each section of the plant recorded the necessary data. Thus, the required information was obtained very easily and cheaply without any interference with production. Since it was known which rinses were routed to the alkali waste lines, it was easy to calculate the total flow rate to these lines. Checks on the flow rates so calculated were obtained by gaging sump tanks, into which the wastes drained by gravity and from which the wastes were transferred by pumps.

TABLE III.—Flow Rates of Waste Discharges

Waste	Flow Rate		Remarks
	(g.p.h.)	(g.p.d.)	
Silver	—	5,000	
Acid	4,500	40,000	Flow rate constant, 7 AM to 4 PM; essentially zero flow during night shifts.
Alkali	12,500	160,000	Flow rate constant at 12,500 g.p.h., 7 AM to 4 PM; flow on night shifts and total daily flow variable depending on production.

The flow rates of the various waste discharges are summarized in Table III.

Determination of Waste Compositions

In undertaking the survey of waste compositions, it was decided first that the wastes would be analyzed for free cyanide, total cyanide, and heavy metals (particularly copper, zinc, nickel, and silver); that is, the wastes were to be analyzed only for toxic materials and potentially recoverable materials. Estimates of the compositions of the wastes with regard to kerosene, soaps, orthosilicates, etc., were made from information on the frequency and procedure for making up the various baths in the plant. This procedure provided information on both the instantaneous and average concentrations of toxic and recoverable materials, but it provided only long-term composite concentrations of other materials. These proved adequate, however, since the problem of developing treatment methods was approached by applying each treatment method to a variety of waste samples in order to make certain that it would satisfactorily remove toxic and recoverable materials regardless of the nature and concentration of other materials present. The compositions of the various waste discharges are given in Table IV.

Total cyanide in the wastes was determined by distillation, according to the method developed by A.E.S. Research Projects 2 and 10 (1). Free

TABLE IV.—Composition of Waste Discharges

Waste	Type of Sample	Component	Concentrations (p.p.m.)		
			Min.	Max.	Av.
Silver	Spot	Silver	6	2,000	270
	Spot	Copper	3	900	12
	Spot	Nickel	0	30	5
	Spot	Zinc	0	25	9
	Spot	Free cyanide	3	2,800	116
	Spot	Total cyanide	9	3,940	155
Total acid	—[1]	Sulfuric acid	—	—	1,740
	—[1]	Nitric acid	—	—	2,020
	—[1]	Hydrogen chloride	—	—	243
	—[1]	Caustic soda	—	—	14
	—[1]	Sodium bichromate	—	—	4.8
	Spot	Silver	—	—	1.1
	Spot	Copper	30	590	135
	Spot	Nickel	10	130	33
	Spot	Zinc	5	220	65
	Spot	Iron	—	—	0.4
Total alkali	—[2]	Soap	—	—	270
	—[2]	Borax	—	—	49
	—[2]	Orthosilicates	—	—	40
	—[2]	Caustic potash	—	—	70
	—[2]	Hydrogen chloride	—	—	7
	—[2]	Ammonium chloride	—	—	11
	—[2]	Oakite laundry comp.	—	—	12
	—[2]	K-2 Pennsalt	—	—	34
	—[2]	Oakite-66	—	—	68
	—[2]	Penn-35	—	—	6
	—[2]	Trisodium phosphate	—	—	4
	—[2]	Northwest cleaner	—	—	36
	—[2]	Kerosene	—	—	420
	—[2]	Solventol	—	—	52
	Composite	Total cyanide	7.8	91.5[3]	21.7
	Composite	Copper	3.2	19	6.1
	Composite	Nickel	0.4	3.2	1.9
	Composite	Zinc	0.5	5.1	2.2
	Composite	Silver	—	—	0.2

[1] Calculated from plant records; based on a flow of 40,000 g.p.d.
[2] Calculated from plant records; based on flow of 160,000 g.p.d.
[3] Total cyanide concentration seldom above 20 p.p.m. Monday–Thursday, incl.; high values observed on Fridays as a result of dumpings.

cyanide was determined from the polarogram of a sample of the solution which had been added to 1 g. of sodium hydroxide and 0.05 mg. of methyl red, diluted to 100 ml., and de-aerated by a stream of pure hydrogen. The height of the anodic wave at − 0.20 v. *versus* the saturated calomel electrode is proportional to the free cyanide concentration after the appropriate correction is applied for the contribution of the dissolved silver to the diffusion current at this potential. This is best done by measuring the current at − 0.20 v. and also at − 0.40 v., where only the current due to the silver is found. The difference between these represents free cyanide. Silver, copper, nickel, and zinc were determined polarographically, using cadmium as a pilot ion (2). Iron was also determined by a polarographic method (3).

Spot samples of the silver-bearing wastes or simple composites of spot samples were used for analysis. Since a batch process for recovering silver

was previously indicated, composite samples would have been satisfactory, but there was no convenient way of getting true continuous composites. Spot samples of the acid wastes were preferred, because a continuous process for treating these wastes seemed quite probable. The alkali wastes were so highly variable in composition that it was felt certain that batch treatment or continuous treatment of equalized batches would be used. Hence, composite samples (accumulated over a 4-hr. period by pumping from the sump into a 50-gal. drum) were used for analysis in this case.

II. Development of Treatment Processes

By Charles A. Walker, Walter Zabban,* Raymond W. Southworth, and E. P. Heslin

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Choice of Cyanide Removal Method

The first problem considered in the development of processes for treating wastes from the Sherrill plant was that of removing cyanides from the wastes. It was realized that the relatively low dilution factor available from the proposed waste disposal plant to Seconondoa Creek (about 10:1 in very dry periods) would make it necessary to discharge treated effluents containing not more than 1 p.p.m. free cyanide and 3 p.p.m. total cyanide. It was also felt that this relatively low dilution factor made it inadvisable to discharge appreciable concentrations of cyanates into the creek. This point can be debated in view of the uncertainty which exists regarding the toxicity of cyanates, but it was considered preferable here to provide for treatment which would produce effluents containing low concentrations of cyanates, unless economic factors indicated that this condition would be very costly to achieve. With these considerations in mind and the results of American Electroplaters' Society Research Project No. 10 (4) (5) at hand it was found that oxidation of cyanides by chlorine or hypochlorites appeared in this particular case to be the most attractive method for cyanide removal. This method of treatment offers the specific advantages of lower capital costs of equipment as compared with such methods as the use of ozone or ion exchange, and of having been proved in commercial applications to be capable of producing effluents of the quality required in this work.

Silver-Bearing Wastes

The composition of silver-bearing wastes as given in Part I indicated that the proper treatment of this waste discharge should provide for removal of cyanide, recovery of silver in a form suitable for use in the plant or for sale to a refiner, and removal of heavy metals. A relatively small but variable amount of suspended matter contained in the wastes must also be removed to produce a clear effluent. The following methods of recovering silver were considered:

1. Precipitation as the chloride. Precipitation of silver from dilute cyanide solutions as the chloride will occur when chlorine or hypochlorite is used to oxidize cyanides. Thus silver recovery and cyanide removal might be accomplished in a single step.

2. Ion exchange. The recovery of silver on an ion exchange resin and its

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regeneration as a cyanide complex suitable for re-use in the plating baths (5) appeared attractive. The scale of this operation and the relatively small margin between the value of silver as the chloride and of silver in a cyanide solution indicated that the gain in value would not compensate for the chemical control work required.

3. Precipitation on zinc. It was noted in Part I that recovery of silver by exchange on zinc had been practiced in the Sherrill plant for some years. The efficiency of this process was relatively low. Although this might have been improved there was no incentive for such improvement in view of the fact that the effluent from such a process would still contain all of the cyanide which entered with the waste; that is, there would still exist a waste disposal problem.

These considerations indicated strongly that the possibility of recovering silver by precipitation as the chloride should be investigated first.

A review of the literature indicated relatively little information on the commercial feasibility of silver recovery by this method. This lack of information is not surprising, in view of the fact that the method is not applicable to more concentrated solutions because the chloride ion formed from chlorine or hypochlorite may increase the solubility of silver chloride (6) to the point where losses in the supernatant liquid are excessive. The concentrations of chloride ion which result from oxidizing smaller concentrations of cyanide are not sufficient to have an appreciable effect on the solubility of silver chloride.

The results of preliminary experiments on this method indicated a possibility of good silver recovery. It was found, however, that the silver chloride precipitate was very finely divided, making its recovery by sedimentation or filtration rather difficult. Experiments according to the following scheme were undertaken to determine whether chlorination in the presence of previously precipitated silver chloride might yield larger particles with better settling and filtration characteristics:

1. 1000 ml. of the first sample was treated with sodium hypochlorite in a quantity sufficient to supply 3.5 g. available chlorine per gram of cyanide. The solution was stirred slowly for 30 min. to allow time for the cyanide oxidation.
2. The suspension was allowed to settle.
3. 900 ml. of clear supernatant was decanted and analyzed.
4. 900 ml. of a second sample was poured into the beaker containing the precipitate and treated as described above. The process was repeated for a total of 10 samples.

Typical results of these tests are presented in Table V. (It will be noted that at the time of this work cyanide oxidation was being carried only to the cyanate stage. The later decision to oxidize to carbon dioxide and nitrogen required no change in the procedure except as noted in Part III.)

The results of these experiments in-

TABLE V.—Typical Results of Laboratory Experiments on Silver Recovery

Analysis	Treatment No.	Tot. CN (p.p.m.)	Ag (p.p.m.)	Cu (p.p.m.)	Ni (p.p.m.)	Zn (p.p.m.)	Fe (p.p.m.)	pH
Sample	1	102	105	6.5	0.0	6.5	—	9.9
	4	208	250	8	0.5	0.0	—	10.3
	10	156	150	8	3	9	—	11.4
Supernatant	1	0	3.5	4.0	1.2	1.3	0.56	—
	4	0	2.8	12	0.2	3.1	0.57	—
	10	0	1.1	9.8	0.2	1.9	2.6	—

dicated the proposed process to be satisfactory as regards cyanide oxidation and silver recovery. Furthermore, it was noted that the chlorination in the presence of previously precipitated sludge yielded a precipitate of improved settling characteristics. The removal of heavy metals was not as complete as might be desired. It had been decided at this point, however, that the waste disposal plant would be so arranged that all smaller discharges, such as the supernatant from silver recovery, would be mixed with the main raw waste discharges rather than being dumped directly into the creek. This arrangement would leave the operator responsible for the quality of only one effluent from the plant. Thus, complete removal of heavy metals during the silver recovery process was not necessary.

The silver recovery process was further investigated with larger batch sizes (5 gal. and 500 gal.). The results of these investigations confirmed the previous conclusions.

Alkali Wastes

Preliminary experiments on processes for treating the alkali wastes indicated that the most promising method would involve skimming to remove some kerosene, soaps, etc., oxidation of the cyanide by chlorine or sodium hypochlorite, acidification to "break out" emulsified oils, skimming, and precipitation of heavy metal hydroxides by the addition of lime. In order for this process to be satisfactory it was necessary that the final heavy metal hydroxide floc serve to clarify the wastes of suspended soaps, etc. The degree of clarification which can be obtained with a floc is, of course, dependent on the concentration of the floc. It was therefore necessary to determine whether the metals present in the alkali wastes would provide enough floc for effective clarification or whether additional heavy metal would be necessary. Such additional heavy metal might be supplied by the addition of alum or a ferric salt. Another possible source of heavy metals for floc formation was the acid waste, which contained appreciable concentrations of copper, nickel, and zinc.

In carrying out laboratory-scale treatments of alkali wastes from the Sherrill plant, it was the usual practice to add sodium hypochlorite (7.5 g. available chlorine per gram of cyanide) to the raw wastes without a preliminary adjustment of the pH, since the data indicated that the pH was usually between 8 and 11, a range in which cyanide oxidation is complete within a short time. The rate of cyanate oxidation, on the other hand, was known to be very slow at pH 11, to require several hours for completion at pH 8.5, but to be quite rapid at pH 6.5. Provision was made in the treatment method for taking advantage of this effect of pH on the rate of cyanate oxidation.

Two methods were used in typical laboratory-scale treatments of the alkali wastes. Method No. 1 involved the following steps:

1. Addition of sodium hypochlorite.
2. Agitation for 10 min. to allow time for oxidation of cyanide to cyanate.
3. Addition of ferric chloride solution to pH 6.5.
4. Agitation for 10 min. to allow time for oxidation of cyanate.
5. Addition of ferric chloride solution to a total of 200 p.p.m. Fe.
6. Skimming.
7. Addition of lime slurry to pH 8.
8. Settling of floc.
9. Decanting.

Method No. 2 was the same except that in place of the ferric chloride solution acid wastes were substituted in Step 3 for pH adjustment to 6.5, and in Step 5 to a total of one volume of acid wastes to two volumes of alkali wastes. It

TABLE VI.—Results of Laboratory Experiments on Treatment of Alkali Wastes

Analysis	Treatment Method	Total CN (p.p.m.)	Ag (p.p.m.)	Cu (p.p.m.)	Ni (p.p.m.)	Zn (p.p.m.)	Sludge Volume (%)
Raw waste	1	9.4	0.7	18	0.1	0.3	—
	1	4.2	0.8	14	0.0	4	—
	1	5.2	12	17	0.8	10	—
	2	5.4	25	18	13	8	—
	2	25	8	4.5	2.3	9	—
	2	4	40	16	10	11	—
Supernatant	1	0.35	0.0	0.5	0.6	0.2	—
	1	0.3	0.0	0.1	0.0	0.7	—
	1	0.2	0.0	0.05	0.1	1.1	—
	2	0.2	—	17	0.2	4.8	—
	2	—	0.0	1.5	1.0	0.5	—
	2	—	0.0	2.3	0.9	2.4	—
Acid wastes	1	—	—	—	—	—	4.2[1]
	1	—	—	—	—	—	4.6[1]
	1	—	—	—	—	—	4.5[1]
	2	—	—	240	9	90	4.0
	2	—	—	240	9	90	5.0
	2	—	—	230	15	90	5.0

[1] Coagulation by ferric salt.

will be noted that a high dosage of coagulating agents was indicated in these experiments. Later work showed that ferric chloride dosages as low as 60 p.p.m. Fe were satisfactory and that clarification could ordinarily be accomplished by the use of one volume of acid wastes to four volumes of alkali wastes, the ratio in which these wastes were produced in the plant.

The results (Table VI) indicated satisfactory reductions in the cyanide concentrations of the wastes. Heavy metals removal was quite satisfactory when ferric chloride was used as the coagulating agent, but not when acid wastes were used. However, simple filtration of the effluent was found to reduce the concentrations of the heavy metals to acceptable values. It was thus suggested that sand filters might be necessary in the waste disposal plant if acid wastes were to be used to supply the floc for clarifying alkali wastes. As a matter of fact, sand filters were regarded as excellent insurance against excessive carry-over of heavy metal flocs into Sconondoa Creek.

The proposed method for treating the alkali wastes was thus shown to be satisfactory in regard to removal of cyanides and heavy metals. It was further observed that the process resulted in the conversion of the very dirty waste to a clear colorless liquid. It remained only to show that the cyanide

TABLE VII.—Results of Oxidation of Cyanides in Alkali Wastes

Chlorine Dosage[1] (lb. Cl_2/lb. CN)	Concentration (p.p.m.)				
	Raw	Filtrate			
	Total CN	Total CN	Excess Cl_2	Ammonium, NH_4	Cyanate, CNO
6.5	13.5	0.17	2.0	0.49	5.6
7.5	13.5	0.08	2.7	0.27	1.3
8.5	13.5	0.16	11.3	0.26	1.35

[1] Theoretical chlorine consumption, 100.6 p.p.m.

in the wastes was converted by the process into a harmless form.

Experiments on the alkali wastes were performed to determine whether the cyanate was effectively removed and whether removal of cyanate was by oxidation or hydrolysis. In these experiments the oxidation was carried out at pH 8.2, at which the second stage of the oxidation is relatively slow, requiring about 2 hr. for 90 per cent completion. The time of exposure in these experiments was controlled at 2 hr. The results (Table VII) indicated quite clearly that the cyanate was removed largely by oxidation, not by hydrolysis to ammonium ion.

The alkali waste treatment process was further proved by application to some 50 laboratory batches and to pilot-plant batches as large as 27,000 gal. It was successful in all cases.

Acid Wastes

It is noted in the preceding section that the acid wastes would be treated with lime in the presence of the alkali wastes in order to provide a heavy-metals floc for clarification of the alkali wastes.

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MISSOURI BASIN TREATMENT FACILITY REQUIREMENTS

New or improved waste treatment facilities at 893 specific locations are needed to protect the water resources of the Missouri River drainage basin, according to a recent report by the U. S. Public Health Service. The report, developed cooperatively by the USPHS Missouri Drainage Basin Office and the water pollution control agency of each of the ten Missouri basin states, lists specific project requirements for communities and industries now discharging untreated or inadequately treated wastes into the Missouri and its tributaries. The cost to municipalities and industries of providing these needed improvements is estimated at $186,000,000.

The report summarizes state-developed programs for the 14 sub-basins of the Missouri Basin. These programs have been approved by the Surgeon General as comprising a comprehensive plan which meets the requirements of the Federal Water Pollution Control Act. Under the Act, the USPHS is required to prepare or adopt comprehensive pollution abatement programs, in cooperation with other Federal agencies, state and interstate water pollution control agencies, municipalities, and industries. The Missouri basin is the first major basin in the United States in which this has been done.

Distribution of the report is being made by the state water pollution control agencies of the Missouri basin states and by the U. S. Public Health Service.

GRAVITY SEPARATION OF OIL *

By H. F. Elkin and W. E. Soden

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Considerable work has been done on sedimentation or flotation of suspended particles in liquids since Newton first stated his law of resistance in 1686. Several of the basic studies deal with sedimentation (2)(3)(4)(6)(7), but a few (1)(5)(8)(9) are entirely or primarily concerned with oil separation by flotation.

The evolution of petroleum oil separator design is manifested in the various editions of the A.P.I. "Manual on Disposal of Refinery Wastes" (10)(11)(12)(13)(14). The most recent edition (14) contains a new procedure for separator design based on industry-sponsored research work at the University of Wisconsin (5). The main differences in design criteria from previous recommendations include a change in oil globule diameter of 0.02 cm. to 0.015 cm., use of a single-stage rather than a two-stage basin, increase in allowable mean horizontal velocity of flow from 2.5 to 3.0 ft. per minute, and a clearer definition of terms in the use of overflow rate in sizing the horizontal area. In addition, the arbitrary length criterion of $l + 1.4$ was dropped in favor of a more precise turbulence and short-circuiting factor.

The design of a single-section separator is based on the following three relationships. First, since oil removal is a function of overflow rate, or discharge divided by surface area, and if the rising velocity is equal to the overflow rate, the minimum horizontal surface area can be expressed as

$$A_H = F \frac{Q_m}{V_t}$$

in which F represents the turbulence and short-circuiting factor, Q_m is flow, and V_t equals the rise rate of the 0.015-cm. oil globule (or theoretical overflow rate).

Secondly, the minimum cross-sectional area is governed by a horizontal velocity of flow no greater than 15 times the oil globule rise rate and not to exceed 3 ft. per minute. This relation can be expressed as

$$A_c = \frac{Q_m}{V_H}.$$

Finally, a minimum depth-to-width relationship of 0.3 has been established, or

$$\frac{d}{B} = 0.3$$

in which d represents the effective liquid depth of the waste water and B represents the width of the separator. The recommendations allow depth-width ratios up to 0.5 if this results in a more economical section. It will be noted that this latest design revision has eliminated use of Reynolds number in determining the minimum allowable wetted perimeter of the separator section.

A suggested general arrangement of the new single-section design is shown on Figure 1. Several basic simplifications from previous designs, in addition to the reduction from two stages to a single chamber, are noted. The intricate reverse-flow free-all weir has

* Presented at 25th Annual Conference, Pennsylvania Sewage and Industrial Wastes Assn.; State College, Pa.; Aug. 26–28, 1953.

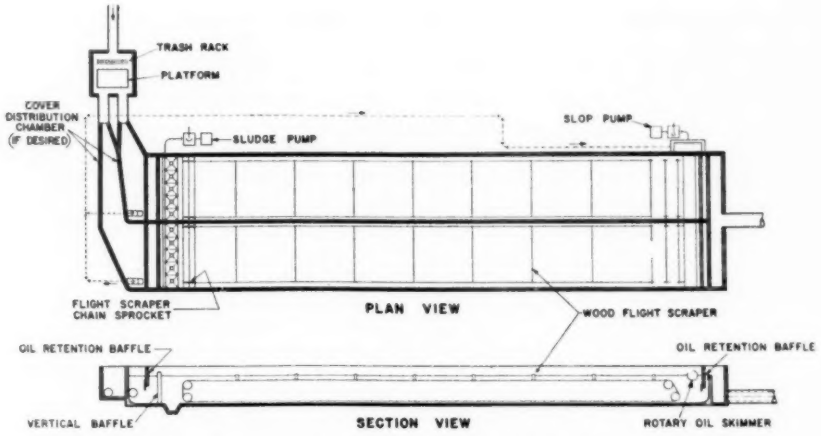

FIGURE 1.—Recommended design (14) for typical oil-water separator.

been replaced by vertical slotted baffles with ⅛-in. or wider orifices. The distribution chamber has been enlarged to introduce flow with a minimum of turbulence and to reduce the high flow velocities in the incoming sewer. The former elliptical oil retention baffle at the effluent end of the separator has been replaced with a simple vertical (or slightly inclined) baffle. Due to the use of a single chamber, only one continuous flight scraper and oil skimmer pipe is required, compared with the two scrapers and skimming pipes in the former two-chamber design.

Marcus Hook Refinery Tests

It is suggested in the latest edition of the A.P.I. Manual (14) that existing separators can be modified by altering over-all dimensions, removing intermediate baffles, and generally attempting to approach the current design recommendations. Sun Oil Company is converting two two-stage separators at its Marcus Hook, Pa., refinery into two single-stage units. It is believed that this modification will increase the capacity of these units and, in addition, result in improved oil removal efficiency. The conversion to the single-stage unit consists of removing the concrete baffle walls between the primary and secondary chambers and the two reverse-flow free-fall weirs or "bathtubs" in each separator. Vertical pipe inlet distribution baffles with 32 5/16-in. vertical slots are being installed in the front end of each separator.

Since the separators are being converted one at a time, an opportunity was presented of comparing the oil removal efficiencies of the single-stage with the two-stage unit operating in parallel when the first separator conversion was completed. A series of field tests was arranged, therefore, to operate the separators at various controlled flow rates with a sampling and testing procedure as described later. Figure 2 shows plan and section views of the two separators during the test period when one of the separators had been converted into a single-stage unit.

The field tests were carried out on successive days, when the two separators were operated in parallel at horizontal velocities of 0.5, 1.0, 2.0 and 3.0 ft. per minute for periods of 5 to 8 hr., and sampled for oil contents simultaneously. Since the normal dry-weather flow in the separators produces

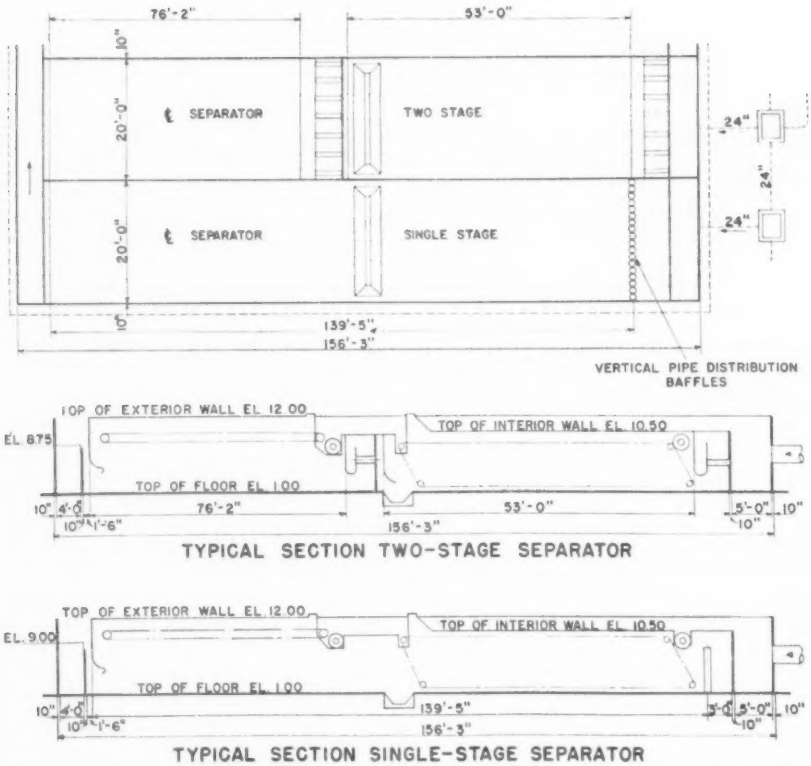

FIGURE 2.—Plan and sections of single-stage and two-stage A.P.I. separators during test periods.

a velocity of only 0.25 ft. per minute, it was necessary to add oil-free dilution water from the refinery fire and cooling water systems to achieve the desired test velocities. During each velocity run, a series of spot samples was taken for total oil and S.T.S. (Susceptible to Separation) (15, p. 290) oil content at the front end of both separators; and for total oil, as determined by the Sun semi-micro method, at the effluent weir. The data are given in Table 1, including the calculated efficiency of oil removal and the percentage improvement in total effluent oil content of the single-stage over the two-stage section.

Although comparison tests of longer duration would have been desirable, the results obtained indicated certain general conclusions: First, the single-stage separator produced an effluent slightly lower in oil content than the two-stage unit at horizontal velocities of 1.0 ft. per minute and above. Secondly, both the two-stage and the single-stage separators performed efficiently at all velocities. The two-stage unit had slightly higher efficiencies at the low horizontal velocities of 0.5 and 1.0 ft. per minute, whereas the single-stage separator had slightly higher values at the increased velocities of 2.0 and 3.0 ft. per minute.

The advantages of the newly-recommended single-stage separator over the older two-stage design are as follows:

1. Economy of construction due to reduced requirements for internal steel and concrete walls, baffles, and weirs.

2. Lower loss of head through internal separator equipment. The older two-stage design generally called for a head loss of 3 inches through each reverse-flow weir, or a total internal loss of 6 in. The single-stage separator can be designed with a total internal head loss of approximately 1 in. through the vertical inlet baffles.

3. Ease of cleaning the single-stage unit due to absence of internal baffles and division walls as in the two-stage separator.

4. The single-stage unit shows possibilities of increased oil removal efficiencies. More actual field experience by refiners will be required to substantiate the pilot-scale results achieved in Rohlich's work (5).

Gravity Separator Efficiency and Aids to Gravity Separation

As illustrated by the foregoing efficiency tests, a properly designed and operated oil-water gravity-type separator will perform effectively as long as the influent water meets certain conditions. Giles *et al.* (15) have listed the substances whose presence in a separator influent will limit its effectiveness as follows: (a) oil or solids having specific gravities approximately equal to that of water, (b) emulsions of oil-in-water not readily separable by gravity means, and (c) unusually large quantities of suspended solids.

Methods of controlling the substances that interfere with gravity separation, and at the same time handling other pollutants in the refinery, have been summarized by Weston (16) as:

1. Engineering and process design considerations.
2. Recovery and utilization.
3. Local treatment.
4. Good housekeeping.
5. Effluent treatment.

TABLE I.—Waste-Water Separator Comparative Test Results

Separator	Sample No.	Oil Content (p.p.m.)			Efficiency[2] (%)	Eff. Impr.[3] (%)
		Infl. Total	Infl. S.T.S.[1]	Eff. Total		
		(*a*) 0.5 Ft. per Minute				
Single-stage	1	196	80	30	143.2	
	2	67	41	47	76.8	
	3	106	57	40	134.7	
	Av.	123	54	39	118.3	0
Two-stage	1	220	47	36	106.3	
	2	85	47	34	134.3	
	3	113	59	46	124.2	
	Av.	138	51	39	121.7	
		(*b*) 1.0 Ft. per Minute				
Single-stage	1	6,048	42	38	100.0	
	2	451	83	44	110.6	
	3	138	31	46	86.1	
	4	107	43	32	117.2	
	Av.	1,683	50	40	103.2	13
Two-stage	1	1,393	49	58	99.3	
	2	335	82	48	113.2	
	3	106	44	40	106.5	
	4	81	39	37	104.6	
	Av.	478	54	46	105.9	

TABLE I.—*Continued*

Separator	Sample No.	Oil Content (p.p.m.)			Efficiency[2] (%)	Eff. Impr.[3] (%)
		Infl. Total	Infl. S.T.S.[1]	Eff. Total		
		(*c*) 2.0 Ft. per Minute				
Single-stage	1	800	53	92	94.8	
	2	654	39	72	94.7	
	3	673	36	71	94.6	
	4	355	36	64	92.3	
	5	185	32	46	91.3	
	Av.	533	39	69	93.3	14
Two-stage	1	1,184	80	96	98.5	
	2	906	33	82	94.3	
	3	453	40	80	90.3	
	4	282	33	87	78.4	
	5	236	34	53	90.6	
	Av.	612	44	80	90.5	
		(*d*) 3.0 Ft. per Minute[4]				
Single-stage	1	180	39	19	113.8	
	2	65	16	21	89.8	
	3	67	34	32	107.2	
	4	48	30	34	77.8	
	Av.	90	30	27	97.3	23
Two-stage	1	288	25	37	95.3	
	2	58	22	32	72.2	
	3	46	28	30	88.8	
	4	65	47	43	122.2	
	Av.	114	31	35	94.8	

[1] Susceptible to separation as defined by Giles *et al.* (15, p. 290).

[2] $\%\ \text{Efficiency} = \dfrac{\text{Influent total} - \text{Effluent total}}{\text{Influent total} - \text{Influent S.T.S}} \times 100.$

[3] Per cent improvement of single-stage over two-stage effluent total oil content.

[4] Not run in parallel, but in successive test periods.

All of these pollution abatement considerations are familiar, at least in principle, to the average refiner. Perhaps the oldest-known although most recently-applied approach lies under the heading of engineering and process considerations. An old refinery, with an existing sewer system, presents a difficult problem in waste control, generally due to inadequate capacities and lack of segregation of wastes. It may not be economically feasible or physically possible to completely redesign the drainage system of an existing plant, although many comparatively simple alterations (such as excluding certain oil-free storm and cooling waters) may be effected, thereby reducing the load on oil-water separators. Because of the lack of segregation of wastes and the resulting presence of interfering substances in the combined wastes-water flow to gravity-type separators, the burden of improvement to waste-water quality in an old refinery falls on costly and difficult effluent treatment.

Construction of a new refinery, or a new plant in an existing refinery, presents an opportunity for the design and installation of a sewer system that will effectively segregate and collect wastes according to their characteristics. A system of classification of sewer sys-

tems and waste waters in a new refinery as recommended in the A.P.I. Manual (14) is shown in Figure 3. The various collecting systems are as follows:

1. Contaminated Storm-Water Sewer System. The contaminated storm-water sewer system collects surface water from refinery drainage areas, such as processing and tankage areas, which normally contact oil, and conveys it to the storm-water separator. This water normally contains varying quantities of separable oil, but little or no emulsified oil and chemical contaminants. Peak separator loads may be reduced by controlling the run-off of diked areas or by providing surge volume (an impounding basin).

2. Contaminated Cooling-Water Sewer System. Once-through cooling water from condensers and coolers—when the oil being processed is a condensible product which will not vaporize rapidly on exposure to the atmosphere (C_6's and heavier)—is sewered to the contaminated cooling-water separator. This water will normally be free of oil except in the event of leakage through tubular equipment.

3. Oil-Free By-Pass Sewer. The oil-free sewer collects waste waters which never have contact with any oil, and by-passes them around the separators to the refinery effluent water sewer. This drainage system includes uncontaminated storm water, cooling water not subject to oil contact, water treatment plant wastes, roof drainage, and once-through cooling water from condensers and coolers handling gaseous products (C_5's and lighter).

4. Sanitary Sewer System. Untreated sanitary sewage should be excluded from waste-water separators because its presence is likely to interfere with sedimentation and separator effectiveness. The sanitary sewer system collects raw sanitary wastes and conveys them to municipal sewers or to treatment facilities within the refinery.

5. Process-Water Sewer System. The process-water sewer system collects all waste waters which come in direct and continuous contact with oil and which are subject to emulsified oil content.

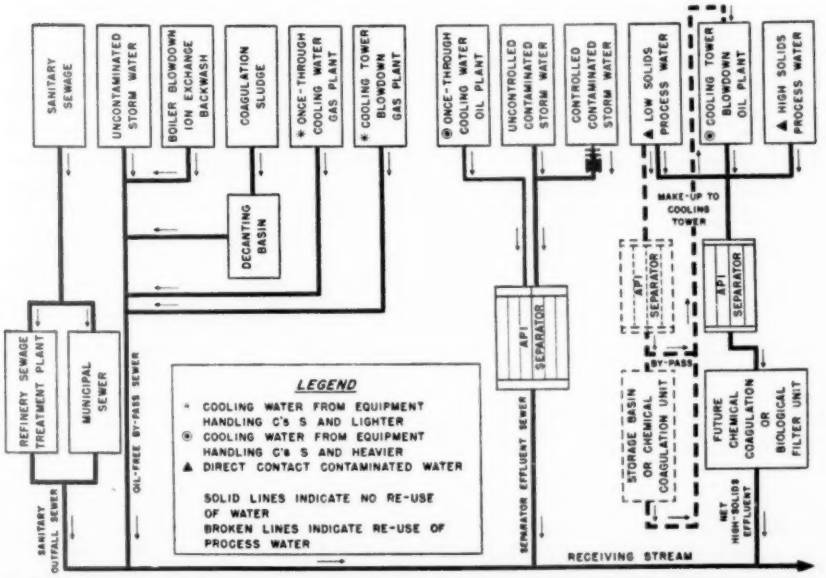
SANITARY SEWAGE
UNCONTAMINATED STORM WATER
BOILER BLOWDOWN ION EXCHANGE BACKWASH
COAGULATION SLUDGE
* ONCE-THROUGH COOLING WATER GAS PLANT
* COOLING TOWER BLOWDOWN GAS PLANT
◉ ONCE-THROUGH COOLING WATER OIL PLANT
UNCONTROLLED CONTAMINATED STORM WATER
CONTROLLED CONTAMINATED STORM WATER
▲ LOW SOLIDS PROCESS WATER
◉ COOLING TOWER BLOWDOWN OIL PLANT
▲ HIGH SOLIDS PROCESS WATER
MAKE-UP TO COOLING TOWER
DECANTING BASIN
API SEPARATOR
API SEPARATOR
API SEPARATOR
BY-PASS
REFINERY SEWAGE TREATMENT PLANT
MUNICIPAL SEWER
OIL-FREE BY-PASS SEWER
STORAGE BASIN OR CHEMICAL COAGULATION UNIT
FUTURE CHEMICAL COAGULATION OR BIOLOGICAL FILTER UNIT
LEGEND
* COOLING WATER FROM EQUIPMENT HANDLING C's S AND LIGHTER
◉ COOLING WATER FROM EQUIPMENT HANDLING C's S AND HEAVIER
▲ DIRECT CONTACT CONTAMINATED WATER
SOLID LINES INDICATE NO RE-USE OF WATER
BROKEN LINES INDICATE RE-USE OF PROCESS WATER
SANITARY OUTFALL SEWER
SEPARATOR EFFLUENT SEWER
NET HIGH-SOLIDS EFFLUENT
RECEIVING STREAM

FIGURE 3.—Flow diagram for the segregation and treatment of refinery waste waters.

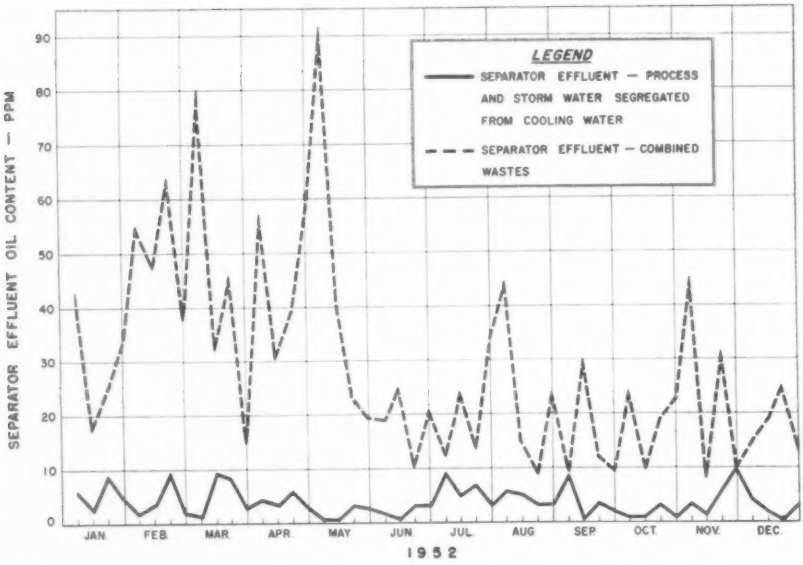

FIGURE 4.—Comparison of gravity separator effluents when operating on combined wastes and segregated wastes at the Marcus Hook refinery, 1952.

Chemical wastes may be included in this collecting system. A gravity separator is provided for primary treatment of these wastes and may be followed by subsequent treatment if required. Following gravity separation, emulsified oil may be removed by chemical coagulation, and chemical wastes with excessive oxygen demands may be treated by biological oxidation. These waters include drawoffs from accumulators and knock-out drums, condensate from steam-stripping operations, desalting waste water, pump-gland leakage and cooling water, barometric condenser waters containing emulsions, cooling tower blowdown, and any other sources known to contain emulsified oil.

Proper segregation of low solids process water from high-dissolved solids process water will permit re-use of low dissolved solids process water as cooling tower make-up. This will lower the oxygen demand of such waste waters and reduce the total volume of waste water leaving the plant.

6. Special Systems. Special collecting systems may also be provided for specific wastes, such as ship ballast water and spent chemical wastes. Such a segregated sewer system has the advantages of (a) reducing gravity separator requirements by by-passing oil-free waters; (b) improving separator effluent quality, by eliminating emulsified oil-bearing wastes from the main drainage system; and (c) reducing secondary treatment requirements, if required, by restricting all emulsified oil- and chemical-bearing waste waters to the relatively small process-water drainage system.

Two separate areas in Sun Oil Company's Marcus Hook refinery offer an interesting comparison between an old plant served by a combined sewer system and a newer plant drained by a segregated sewer system. All contaminated storm, cooling, and process waste water (approximately 2,000 cu. ft. per minute) from the older plant is carried by a single trunk sewer to six parallel separator sections, each having a mean

horizontal velocity of approximately 2.0 ft. per minute. The newer plant has a sewer for approximately 3,000 cu. ft. per minute of cooling water, which passes through six parallel separator sections at a velocity of approximately 3.1 ft. per minute, and a separate sewer for a storm and process waste-water maximum flow of 450 cu. ft. per minute handled in two parallel separator sections at a velocity of 1.4 ft. per minute. The older plant contains crude units, a catalytic cracking unit, lubricating oil, vacuum tower, and gasoline treating facilities. The new plant has a catalytic cracking unit, an alkylation unit, and a gas plant. As shown in Figure 4, the separator effluent oil contents from the combined waste of the old plant run consistently higher (1952 yearly average 29 p.p.m.) than the separator effluent oil contents from the segregated drainage system of the new plant (1952 yearly average 4 p.p.m.) Although it is difficult to make direct comparisons of the type because of variations in plant operations, flow rates, and separator characteristics, the trend toward improved effluent quality through waste segregation is evident.

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PROGRESS REPORT ON SEDIMENTATION STUDY

Sedimentation studies on the fundamentals of settling of solids in tanks, using diatomaceous silica, have brought out the following:

1. A longitudinal wall placed in a settling tank parallel to a side results in slightly higher removals.

2. Decreasing the depth in a settling tank by one-half results in a very significant increase in the removal of solids for identical detention times.

3. Decreasing the depth of a settling tank by one-half results in practically no reduction of the percentage removal of sediment when compared on the basis of identical flow.

4. Data collected on the experimental tank with a well-baffled influent substantiated Hazen's theory that sediment removal is dependent on surface area and independent of tank depth.

The studies, begun in June 1949, are being carried out under a grant from the National Institutes of Health by Professors D. E. Bloodgood and W. E. Howland of Purdue University.

MICROBIOLOGICAL STUDIES ON THE TREATMENT OF PETROLEUM REFINERY PHENOLIC WASTES*

By Waldron D. Sheets, M. K. Hamdy, and H. H. Weiser

Respectively, Research Engineer, Waste Treatment Laboratory; Post-Doctoral Fellow, Department of Bacteriology; and Professor, Department of Bacteriology, Ohio State University, Columbus, Ohio

The project described herein was initiated late in 1951 by the Standard Oil Company of Ohio, which operates four refineries in Ohio, one each at Toledo and Lima and two at Cleveland. Various steps had been taken by the company toward pollution abatement where means were available and studies were being scheduled on wastes requiring special treatment, such as the phenolic condensate from the catalytic cracker. Analyses of samples of this liquor gave the following:

Phenol	100– 400 p.p.m.
Sulfides	2,000–5,000 p.p.m.
Chlorides	200– 300 p.p.m.
Ammonia	200– 500 p.p.m.
Cyanides	20– 30 p.p.m.
pH	8.5

These values are subject to variation, phenols, for example, having been reported as high as 1,300 p.p.m. Volatile petroleum fractions are also present in varying quantities.

The chief concern of the industry was to select an economical method for the reduction of the phenols to tolerable limits.

Literature Survey

Several methods for the treatment of phenolic wastes have been developed and are in use in many industries. Others have been investigated but never applied on a commercial scale. In general the following summary can be made:

1. Extraction. The majority of reports of work done in this field are contained in the German literature, where extensive work was done on the removal of phenols from waste waters obtained in gas works and coal carbonization plants. For the most part, work done in the United States has followed these same lines, with the majority of reported work being on the operation of plants in Germany. Methods for phenol removal from this type waste have been predominantly by extraction methods, as follows:

(a) Solvent extraction—with benzol, light oils, tricresyl phosphate, and mixed organic esters. Regeneration of the extractive medium is accomplished by either distillation or caustic washing.

(b) Distillation—Extraction—Koppers' Method for stream stripping phenols directly from the waste liquor.

In practically all cases the liquor has a fairly high phenol concentration (around 3 g. per liter). About 95 per cent recovery is obtained by these methods and the final clean-up is done usually by some type of biological filter. Final removal also can be accomplished by adsorption with active carbon, although several plants have reported rapid fouling, due to resinous or tarry materials present in the waste. All literature reports indicate that extraction methods are useful only for

* Presented at 123rd Meeting, American Chemical Society; Los Angeles, Calif.; March, 1953.

fairly concentrated wastes and some other process must take over in the low ranges. For refinery purposes extraction would appear promising only for concentrated waste waters, with final lowering perhaps possible by dilution with other waste waters free of phenols.

2. Adsorption. Active carbon, for taste and odor control in water treatment, has been the most widely used adsorbent and as far as commercial installations are concerned is the only one reported. In water treatment the charcoal is added prior to sedimentation and is removed as sediment. Several instances are noted where charcoal is used for cleaning up gas plant wastes after extraction, with regeneration of the charcoal being accomplished by steam or benzene.

Other adsorbents listed in the literature are norites, coal ash, and galena. One plant employs powdered coal as an adsorbent followed by froth flotation for separation of the coal-phenol, the coal being used for normal boiler requirements. A patent lists the use of ion exchange resins (1), but no references were noted in the literature to its actual use.

3. Miscellaneous. Phenols can be removed by electrolysis, precipitation, inorganic acids, catalytic oxidation, and other methods.

4. Biological treatment. This method seems to have great appeal, the Dow Chemical Co., of Midland, Mich., having constructed a full-scale plant utilizing trickling filters (6)(10). The Gary Sanitary District and the U. S. Steel Corporation made some studies at Gary, Ind., utilizing the municipal activated sludge treatment plant (8). The Gary studies gave a summation of data of particular interest. The following tabulation abstracted from that report represents the monthly average values for phenolic content of the untreated and treated liquors.

Month	Phenol (lb.) Raw Sewage	Final Effluent
October	—	—
November	341	0.31
December	432	0.59
January	694	0.75
February	836	0.52
March	914	0.26
April	1,578	0.31

In general, the literature does not reveal any biological data, or why biological processes can effectively reduce phenols. With reference to the Gary data as tabulated, it will be noted that the pounds of phenol remaining in the final effluent indicate that some change took place in the biological balance during the studies. If these values are plotted as a curve, pounds *versus* time, the curve first rises and then falls for the latter half of the test period, even though the phenolic content of the raw sewage increased approximately five times over the same period. This indicates that the microorganisms responsible for the destruction of phenol either increased or adapted themselves to better utilization of the phenol. The same data initiated the assumption that oxidation of phenol by the use of air alone was not entirely responsible for the loss of phenol in the process.

If these statements are true then why wouldn't a study of the responsible organisms be appropriate? If sufficient data could be acquired perhaps a betterment of the environmental conditions would increase the efficiency of the process. Investigation of the bacterial growths and their action was thus indicated.

Procedure and Methods

To study the bacterial action a small pilot plant was constructed in which typical growths were to be developed. This plant (Figure 1) consisted of a feeding system and a trickling filter followed by a small settling tank. The filter bed was prepared of 2½- to 4-in. limestone.

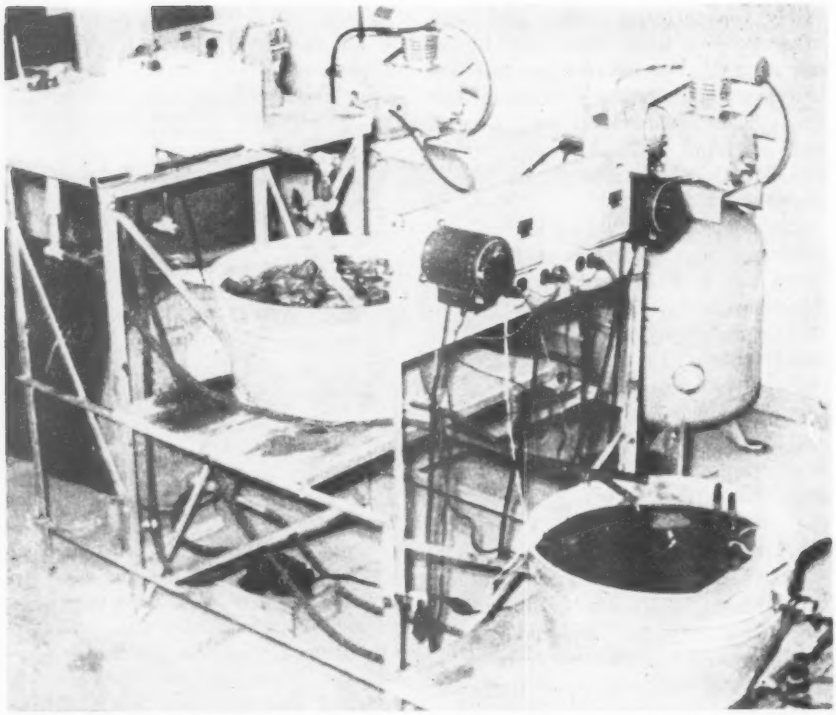

FIGURE 1.—Trickling filter pilot plant, showing weir boxes and solution feeder (top left), trickling filter (center), electric safety devices and pump speed regulators (center), and settling tank (lower right) with immersion heaters.

To provide the flow necessary to drive the distributor, treated waste liquor was recirculated; the applied liquor consisted of three to four parts of recirculated liquor to one part of settled domestic sewage, the sewage providing a natural seeding microflora for the filter bed. The final adjusted flow had a volume of 1.0 to 1.3 l. per minute.

Continuous operation of the unit began in June, 1952, and it has been in full operation since that time except for a few interruptions necessary for maintenance.

Bacteriological studies were begun as soon as the growths (Figure 2) of the organisms developed on the filter stone. A few *Psychoda* were observed. Drums of the phenolic condensate were shipped from Lima, Ohio, at regular intervals and this liquor was added to give approximately 25 p.p.m. of phenol in the filter feed.

The high sulfides were an immediate concern, but nothing unusual happened. The only noticeable effects were a white coating on the filter stone, a large accumulation of sludge present in the effluent, and a milky appearance in the filter effluent due to colloidal sulfur. The pH of the liquor was found to remain at 8.2 to 8.5 at all times.

To treat the condensate before its discharge, the Standard Oil Company had constructed an experimental steam-stripper, which was successful in removing sulfides and also removed a part of the phenols. The concentration of the latter thus became too low to apply to the pilot trickling filter in the concentrations desired and a synthetic phenol solution was therefore

substituted and used throughout the high-temperature studies. This synthetic solution was made of U.S.P. phenol and hydrant water.

Chemical Studies

1. Biochemical Oxygen Demand. The standard Winkler dissolved oxygen test, as applied to B.O.D. determinations, was used in the preliminary stages, but only a few analyses were tried before it was discovered that the sewage and phenolic condensate mixture had a high and rapid iodine demand. Previous experience under similar conditions (11) recommended elimination of further B.O.D. determinations.

2. Oxygen Consumed. To obtain reductions in the strength of the waste without the use of the B.O.D. test, the dichromate method of determining oxygen consumed (9) was used. This has given satisfactory and consistent results.

3. Phenols. For phenols, two methods were used, the *p*-nitrosodimethylanaline and the 4-aminoantipyrene.

The former was recently developed by Hill (7) and has had little chance for use by other investigators. The latter method was used by Dannis (4) and will appear in the new edition of Standard Methods (12). It was also adopted recently by A.P.I. to take the place of the Gibbs method.

Both of the foregoing methods are basically similar in that the Gibbs distillation procedure is used to eliminate interference from such substances as sulfides, strong oxidants or reductants, acids and alkalis, and some non-phenolic aromatic compounds. Both methods also use an extraction procedure for increasing the sensitivity in use on phenol concentrations down to 5 p.p.b.

The *p*-nitrosodimethylanaline method was used for the major portion of the studies. In the latter part of the work this method compared favorably with the 4-aminoantipyrene method. Analyses by either of these two methods,

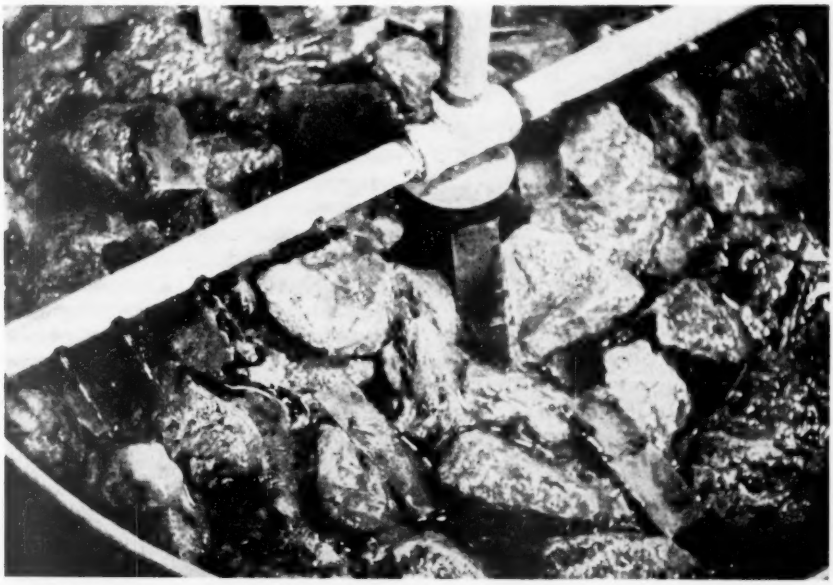

FIGURE 2.—Filter stone, showing growth on stone and on microscope slides.

however, should be made carefully by the analyst; it was definitely determined that experience is one of the prerequisites of both methods.

Bacteriological Studies

Glass microscope slides were placed on the stone at several points and after seven days were removed. The growth was washed from a slide with distilled water and used to inoculate tryptone-glucose agar medium. The growth on the glass slide was similar to those on the filter stone and the slide, having a fixed area, assisted in making comparative counts. The tryptone-glucose agar medium served as the initial step in the isolation and partial identification of the different varieties of bacteria. Standard bacteriological procedures were followed in all cases.

After the initial conditioning of the filter, and in the absence of phenol, 26 varieties of aerobic bacteria and 8 varieties of anaerobic bacteria were isolated from the growths developed on the filter stone. All of the anaerobic varieties were found to be facultative.

No attempt was made to identify the higher forms of life and the bacteria normally associated with the filter bed. However, a detailed study was made on the phenol-resistant organisms and their ability to utilize phenol in varying concentrations.

It was noted that phenol concentrations up to 200 p.p.m. were tolerated by large numbers of the organisms mentioned. Increasing the concentration of phenol on the filter caused a marked decrease in the total count of microorganisms; however, the count increased as the organisms selectively developed tolerance for phenol.

To determine the maximum tolerance, mixed cultures from the filter were transferred to tubes containing phenol-litmus milk medium. The studies were made under both aerobic and anaerobic conditions, the latter condition being obtained by applying a sealing layer of agar over the inoculated medium to secure anaerobiosis. Phenolic condensate was originally used, but due to the difficulty of obtaining the exact concentrations desired, a standard solution of U.S.P. phenol was substituted and used for the medium preparation.

At a concentration of about 900 p.p.m. there were three unidentified organisms able to tolerate this concentration of phenol; namely a *Bacterium*, a *Streptococcus*, and a spore-forming *Bacillus*. It should be stated here that the same three organisms were the only survivors on the filter media, although subjected to phenol concentrations of approximately 400 p.p.m. with longer contact periods.

Growths under aerobic conditions were not evident at a concentration of 3,700 p.p.m., as indicated by the color of the litmus milk medium when compared with a sterile control tube. Bacterial growth was observed by acid production and gas formation, the former changing the color of the litmus from an original blue to red.

Under anaerobic conditions the growth continued to a concentration of 4,800 p.p.m. The phenol content reported represented free phenol uncombined with the casein of the milk. This was verified experimentally when phenol was completely recovered from the control tubes.

Berger and Wyss (2) reported *Micrococcus pyogenes* var. *aureus* developed resistance to the bacteriostatic action of phenol up to the range of 2,000 to 3,000 p.p.m. Ergrova (5) reported a *Bacillus thermophenolicus* whose growth decreased at a phenol concentration of 3,000 p.p.m. and it was this latter reference which induced the trend of the present studies to the thermophilic range.

In January 1953 a series of bottle tests was devised to determine the ability of the bacteria to reduce phenol in a standard phenol solution at various temperatures and paralleling the pilot-plant operation. Standard dilution bottles were used, a settled

sewage and phenol mixture of 200 p.p.m. phenol concentration forming the culture medium. Each bottle was inoculated with 1 ml. of a solution, obtained by washing glass slides, which had been subjected to about seven days of exposure on the surface of the filter, containing the microorganisms growing under the current filter conditions. Each set of bottles included one control and three inoculated samples, the latter to be incubated at 20°, 37°, and 54° C., respectively, the control being incubated at each temperature in succession. At 24-hr. intervals, 10 ml. of liquid was taken from each bottle and analyzed for phenolic content.

Within a short period of time these experiments produced some interesting results. The control showed some variation, probably due to errors in the analysis, but no appreciable loss. The bottles incubated at 20° C. indicated a reduction of no more than 10 to 15 per cent phenol in 48 hr. The bottles incubated at 37° C. indicated a reduction of 100 per cent in 60 hr. and the bottles incubated at 54° C. gave a reduction of 100 per cent in 48 hr.

Repetition of these experiments indicated that the time of microbial development on the filter stone was important, as the destruction of phenol gradually increased in the 54° C. group until the 37° C. group were paralleled and finally surpassed in performance.

Pure cultures of the three phenol-resistant bacteria were isolated and it was found that the unidentified *Bacterium* was the form exhibiting the most predominant growth on the filter and that it was responsible for the destruction of the greater portion of the phenol, although the other two organisms present no doubt played an important role in the phenol reduction.

An attempt to complete the identification of these three organisms is under way. Through induced selection and/or mutation these organisms have lost many of their original physiological characteristics, which makes them very difficult to identify according to Bergy (3). With reference to the short rod, it has been classified as of the genus *Pseudomonas*, whereas the long rod and the coccus have been conclusively determined to belong to the genus *Bacillus* and *Micrococcus*, respectively.

Discussion

The pilot plant was not a scale model and the filter was no more than 12 in. deep. In the final stages of operation, however, the growth on the stone was so heavy that only the surface was being used, with ponding taking place over the entire area. From observations of the filter operation at this period it is assumed that a filter no more than 12 in. in depth would be required in a larger installation. The three organisms described were wholly responsible, no other organisms or higher forms of life being evident.

The reduction of phenol in a single pass was found to be from 23 to 28 per cent when operating at 52° to 54° C. The reduction of oxygen consumed at the same time was found to be from 35 to 45 per cent. Tentative loading of the filter has been calculated as 1 lb. of phenol per square yard of filter area per day. A recirculation ratio of 4 to 1 is advisable.

Coe (13), working on bench-scale biological oxidation of refinery wastes with activated sludge, reported that the treated product of the wastes was usually light yellow (similar to the color noted in these studies during phenol oxidation), which disappeared after ½ hr. of complete phenol destruction. This color was found dependent upon pH, since it disappeared upon addition of acid and reappeared upon the addition of sodium bicarbonate. It can be stated that this yellow compound seems to be an intermediate in the oxidation mechanism of phenol.

Coe (13) also stated that the rate of growth of the floc was low, which seemed to be comparable to growth behavior observed in the present investi-

gation, but which was controlled by temperature regulation as shown by the increase in growth on the filter at the higher temperature used.

Conclusions

1. Biological treatment of wastes for the reduction of phenol can be accomplished with increased efficiency by the use of temperatures in the thermophilic range, 52° to 54° C.

2. Three principal microorganisms were found to be present; these phenol-resistant organisms were responsible for the destruction of phenol.

3. The initial seeding of the filter requires sewage, but after the filter growth has developed some resistance to phenol, the addition of domestic sewage should be eliminated.

Acknowledgments

The authors wish to acknowledge the timely assistance and interest in the project of L. J. Griffith, Graduate Assistant, and E. L. Sherrer, Graduate Student, Department of Bacteriology, and Victor V. Elliott, Senior, College of Engineering, the Ohio State University.

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INDUSTRY REPRESENTATIVE ON POLLUTION ADVISORY BOARD

Thomas J. Powers, supervisor of waste disposal for the Dow Chemical Company, has been appointed by President Eisenhower as industry representative on the water pollution control advisory board of the U. S. Public Health Service. The Board serves in an advisory capacity to the Surgeon-General on policies and programs of the Public Health Service under the Pollution Control Act.

Mr. Powers will replace L. A. Danse of General Motors, who has served on the advisory board since 1949.

RADIOACTIVE CONTAMINATED LAUNDRY WASTE AND ITS TREATMENT

II. Treatment by Continuous Flow Over Slimes

By Earnest F. Gloyna

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In planning a program for the treatment of laundry waste, it is necessary to regulate the materials used in the decontamination of fabric so that the subsequent waste water may likewise be successfully decontaminated. Good results in the decontamination of clothing depend largely upon the selection of chemicals used to remove the radioactive particulate matter. The selection of cleansing agents, therefore, must not jeopardize the effluent control program. Accordingly, the ideal cleansing agent is one which satisfactorily removes unstable trace elements and at the same time aids the biological treatment of liquid wastes. Conditions must be favorable for biological floc or slime formation, because slime films in biological treatment units not only have the ability to oxidize organic matter directly and to absorb organic matter into settleable sludges, but also may assimilate some of the radioactive elements.

To establish a criterion for radioactive-contaminated laundry waste treatment, experimental evidence was necessary. This criterion might also be used in the selection of detergents for laundering. Experiments were designed, therefore, in such a way that a screening survey of the major contaminants could be obtained prior to setting up basic laboratory slime investigations. Following these exploratory experiments (5), which were initiated with the growing of organisms suspended in agitated solutions, surface slimes were grown to investigate the treatability of radioactve-contaminated, synthetic laundry wastes. These realistic laboratory techniques utilized rotating tubes. After data were obtained from the rotary-tube slimes, correlation experiments were performed with a small, laboratory-type trickling filter to show the similarity between rotating tubes and orthodox trickling filters.

The constituents of synthetic laundry waste preparations affected the growth and viability of slimes in several different ways. Some of the synthetic laundry materials were utilized and caused no serious inhibiting effects; others were utilized but were toxic; whereas still another group was not utilized and had varying toxic effects on the organisms. For example, citrate (even at low pH values and high concentrations) was utilized to the same extent as synthetic nutrient or domestic sewage under equivalent conditions. On the other hand, Igepal (a detergent) and Versene (a chelating agent) were not attacked by organisms, but exhibited mild to serious slime-destroying tendencies. Two other detergents, Tide and Rinso, were attacked by organisms and inhibited the growth of biological slimes to varying degrees.

Seven radioactive isotopes were likewise added to various wastes; and the detention of these isotopes by biological slimes was studied with the use of tracer techniques. The radioactive isotopes were: P^{32}, I^{131}, Sr^{89}, Ce^{144}, Cs^{134}, and Ru^{106}. The isotopes P^{32}, Ce^{144}, Sr^{89}, and I^{131} were partially detained in these slime tubes.

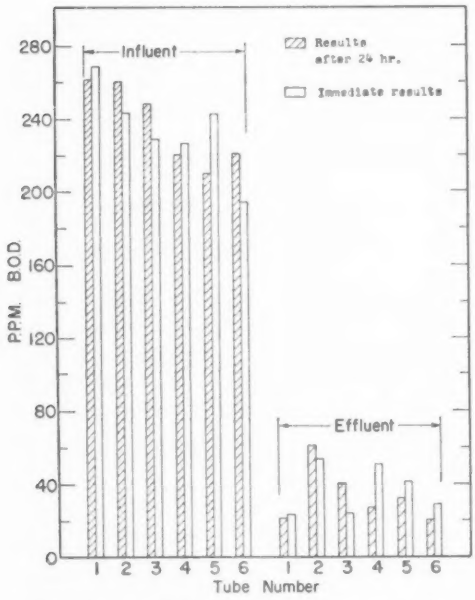

FIGURE 1.—Effect of time on feed solution.

Special Techniques Developed

Surface slimes were first grown under aerobic conditions, at constant temperature (23° C ± 1°), and were subjected to a variety of synthetic waste preparations. Specific control of the waste was obtained by use of a synthetic nutrient which added about 225 p.p.m. of B.O.D. to the laundry waste. The synthetic nutrient consisted of peptone, beef extract, urea, and inorganic salts. Synthetic nutrients and wastes were generally used throughout the experiments in order to eliminate the possibility of interference from foreign debris such as is commonly found in domestic sewage and regular laundry wastes. The silts and other foreign debris were objectionable because this investigation was primarily interested in the role played by trickling filter organisms. The fresh synthetic nutrients and laundry wastes were seeded prior to treatment, thus producing in the treating unit a biological population with sufficient heterogeneity to adapt to varying environmental conditions.

A fresh waste was prepared each day, and the sampling procedure consisted of taking one set of samples daily. The error produced by this method of sampling proved to be slight (Figure 1).

The primary method used in studying the utilization of synthetic nutrient, the utilization of laundry wastes, and the detention of radioactivity by slimes was a specially developed apparatus (1). The basic units, in which slimes were grown, consisted of six plastic, horizontal, rotating tubes. All six tubes were 2 ft. long, 2½ in. outside diameter, and 2¼ in. inside diameter. The tubes were mounted on a base, the slope of which was adjustable. The effluent was introduced at the rate of 7 l. per day, or 1 drop per second, and revolved down through the slime tubes to a collection point. A lip, consisting of a plastic attachment which was ¼ in. wide and ⅛ in. thick, was

provided at the effluent end of the tube to prevent run-back of radioactive liquids. The small rotary tubes have the following advantages:

1. Slimed areas were known.
2. Biochemical oxidation efficiencies were readily controlled.
3. Biochemical equilibria were obtained in a very short time.
4. Relatively small amounts of contaminated wastes were required.
5. Slimes are formed and reach equilibrium in relatively short periods of service.

Actual operation of rotary tubes with synthetic nutrients revealed that a high degree of purification could be obtained in a relatively short time. Table I shows an average B.O.D. removal of 85 per cent with an average B.O.D. application of 258 p.p.m. A mathematical and experimental correlation showed that an application of 7 l. per day of domestic sewage through the rotary tubes would be equivalent to a dosage rate of about 8 m.g.a.d. for a conventional trickling filter having a depth of 6 ft. and an average media size of 2 in. An important characteristic of rotating tubes utilizing the synthetic nutrient was that only seven days were required to reach equilibrium.

The time required for passage of the liquid through the rotating tubes followed a typical frequency distribution pattern. A right-skewed distribution curve (Figure 2) occurred as the result of plotting counts of I^{131} per minute per milliliter of effluent *versus* time. Zero time represents the time when a few drops of high count I^{131} were applied to the influent. The observed detention times for liquid passing through a rotary tube containing a sewage-fed slime had a mode of 18 min. and a mean of 57 min.

A laboratory-type trickling filter was another device used in the slime-growing experiments. This unit consisted of two 4-ft. plastic tubes with the same diameters as the rotary tubes. The two sections of the trickling filter were placed in a vertical position so that operation was in series with an intermediate air gap. A constant head and dripping arrangement supplied the influent at a rate of 1 drop per second. The rock media used was rounded gravel, which had been carefully washed and screened so that it all passed a 0.525-in. screen opening and was detained on a 0.371-in. screen opening. The trickling filter attained a very high degree of purification, but required a long time to attain equilib-

TABLE I.—Nutrient Utilization by Slimes

Unit	No. of Tests	B.O.D.		NH_4–N		NO_2–N		NO_3–N		Total N	
		Appl. (p.p.m.)	Rem. (%)	Infl. (p.p.m.)	Effl. (p.p.m.)	Infl. (p.p.m.)	Effl. (p.p.m.)	Infl. (p.p.m.)	Effl. (p.p.m.)	Infl. (p.p.m.)	Effl. (p.p.m.)
(*a*) Rotary Tubes											
No. 1	6	265	87	25.3	65.6	Neg.	Neg.	Neg.	Neg.	91.0	87.0
No. 2	7	260	82	34.6	50.3	—	—	—	—	85.8	81.1
No. 3	8	244	83	26.6	54.8	—	—	—	—	87.2	80.0
No. 4	7	251	83	26.4	47.0	—	—	—	—	89.8	83.0
No. 5	6	246	82	26.3	59.8	—	—	—	—	88.1	80.0
No. 6	8	245	83	28.0	59.0	—	—	—	—	88.3	81.4
(*b*) Trickling Filter											
1	14	265	92	20.3	33.8	—	3.3	—	8.6	85.7	88.0

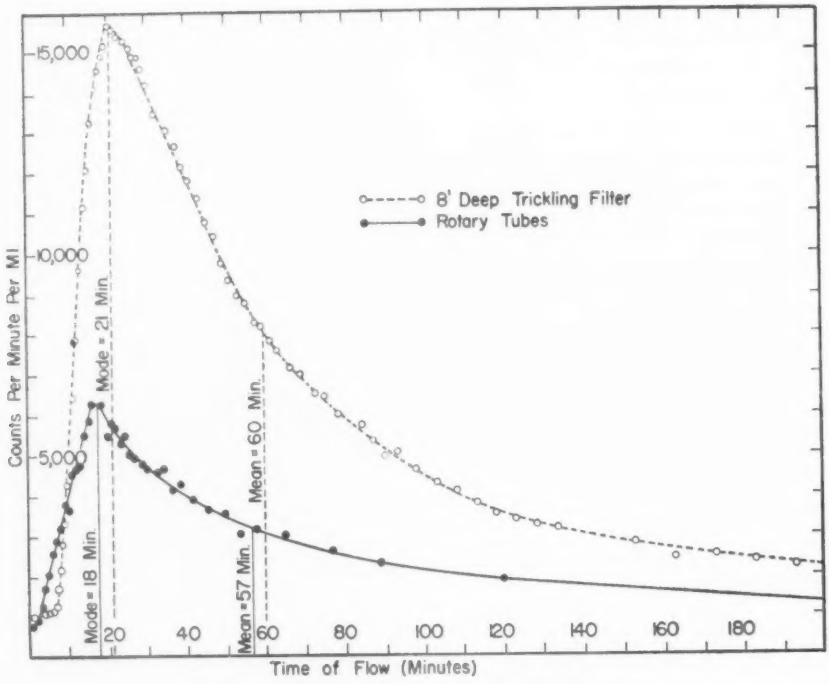

FIGURE 2.—Variation of I^{131} in effluent with time.

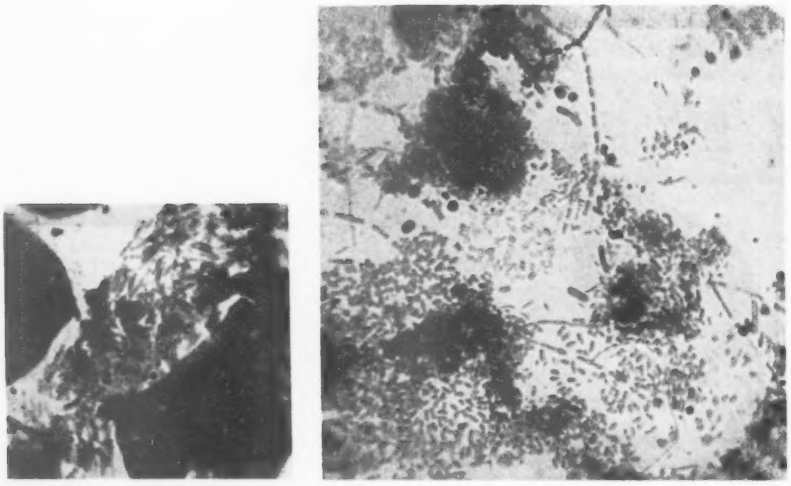

FIGURE 3.—Photomicrographs (× 950) showing Gram-negative organisms (left) grown in rotary slime tubes with a solution containing synthetic nutrient and 500 p.p.m. of citrate at pH 7.0, and (right) found in the activated sludge liquor of the Back River sewage treatment plant, Baltimore, Md.

rium. The average B.O.D. reduction attained with synthetic nutrient was 92 per cent when the initial B.O.D. was 265 p.p.m. The major difficulty in trickling filter operation was that it required about 15 days or more to reach equilibrium.

The flow-through time was also measured in the trickling filter with I^{131}. The mode and mean flow-through times (Figure 2) were 21 and 60 min., respectively. It was a coincidence that the times corresponded closely to the values attained for the rotary tubes.

Similar populations of organisms which were grown in these different experimental devices showed some likeness to those found in sewage treatment plants. Evidence that organisms developed by the experimental units were indeed similar to those found in the regular sewage treatment plants is

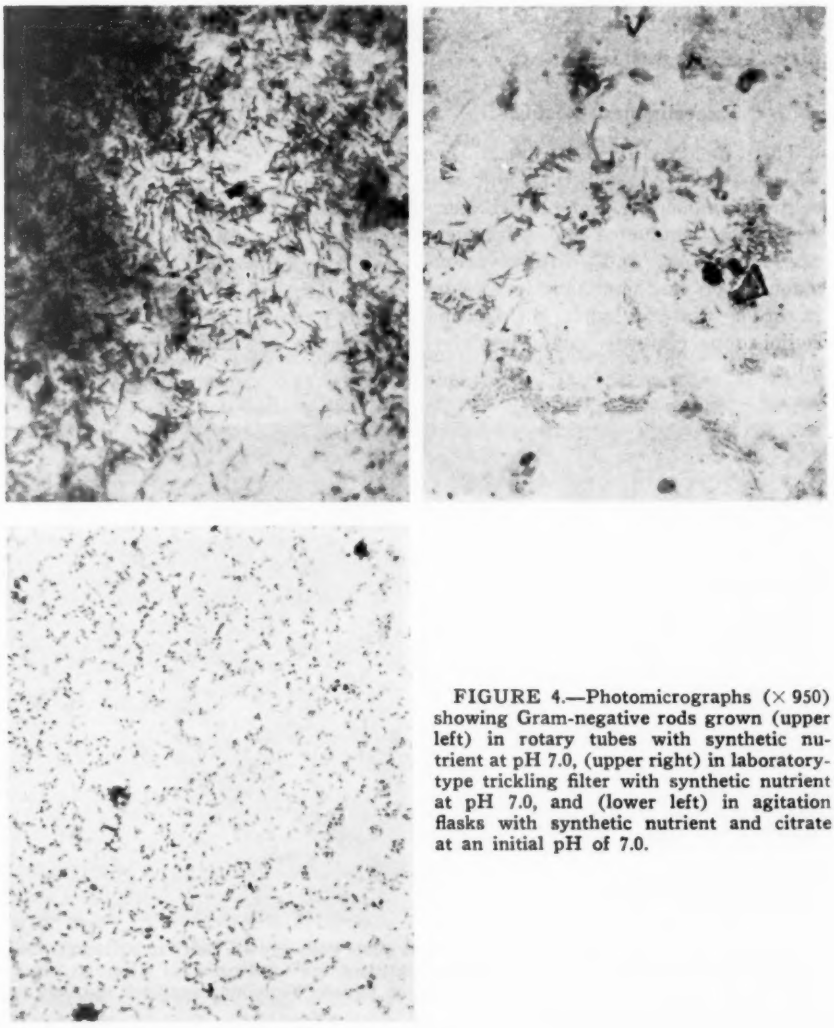

FIGURE 4.—Photomicrographs (× 950) showing Gram-negative rods grown (upper left) in rotary tubes with synthetic nutrient at pH 7.0, (upper right) in laboratory-type trickling filter with synthetic nutrient at pH 7.0, and (lower left) in agitation flasks with synthetic nutrient and citrate at an initial pH of 7.0.

shown in Figures 3 and 4. Figure 5 shows photomicrographs which record changes that occurred in the type of organism due to changing environmental conditions. The yeasts shown in Figure 5 developed to the same extent in the different types of biological units, and the colors which they developed were the same. In general, the typical coloring of the yeast group was either red or green, whereas the coloring of the non-yeast slimes was dark brown for sewage, light brown for synthetic nutrients, and cream for synthetic laundry wastes.

Experimental Results

The zoogloeal-forming organisms were used to reduce B.O.D. and concentrate radioactive isotopes. Experiments were conducted under a variety of conditions and with various amounts of synthetic laundry wastes in order that optimum B.O.D. and radioisotope removals might be determined.

Waste Treatment with Rotary Slime Tubes

Rotary tube experiments showed that citrate was utilized by the slimes under a variety of pH and organic loading conditions. The effects of different conditions of pH and citrate concentration on B.O.D. removal were performed in two major experiments. In one of these experiments, the average B.O.D.'s in nutrient solution containing 65 and 2,000 p.p.m. of critric acid, as citrate, were 334 and 1,311 p.p.m., respectively. The pH's in the influents, which varied because of the citric acid, were 6.2 and 2.8. The B.O.D. removals for these tests ranged from 83 to 21 per cent. In the other experiment, citrate loading was also varied; but the pH was adjusted to 7.0 and the B.O.D. removed ranged from 81 to 31 per cent. The B.O.D. loadings in these solutions, which contained 500 to 4,000 p.p.m. citrate, respectively, ranged from 495 to 2,920 p.p.m. The results of both experiments are further represented in Table II.

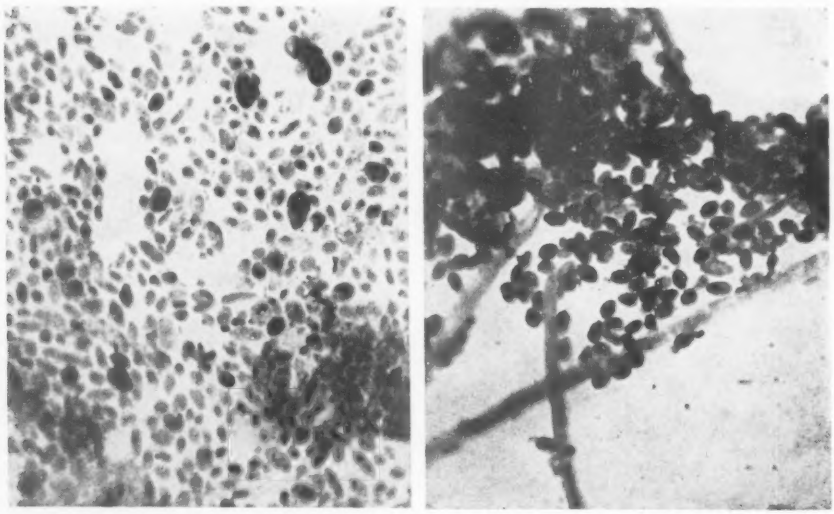

FIGURE 5.—Photomicrographs (× 950) of yeast cells grown (left) in agitation flasks with a solution initially containing synthetic nutrient and 4,000 p.p.m. of citrate at pH 2.4 and (right) in rotary slime tubes with a solution initially containing synthetic nutrient and 2,000 p.p.m. of citrate at pH 2.8.

TABLE II.—Rotary Tube and Trickling Filter Performance

Series No.	No. of Tests	Investigational Device	Waste[1] (p.p.m.)	pH		B.O.D.		NH_3–N		Tot. N	
				In	Out	Appl. (p.p.m.)	Rem. (%)	Infl. (p.p.m.)	Effl. (p.p.m.)	Infl. (p.p.m.)	Effl. (p.p.m.)
1	54	Rotary	None	7.0	7.0	258	85	28.0	59.0	88.3	83.4
2	14	Tr. filt.	None	7.0	7.0	265	92	20.3	33.8	85.7	88.0
3 a	12	Rotary	66 Citrate	6.9	7.0	334	82	15.3	58.5	84.4	81.8
3 b	12	Rotary	125 Citrate	4.8	7.0	384	83	15.1	49.6	80.0	80.0
3 c	11	Rotary	250 Citrate	4.0	6.8	438	83	8.7	54.5	69.8	74.6
3 d	12	Rotary	500 Citrate	3.5	4.5	576	44	7.3	32.2	88.1	85.2
3 e	10	Rotary	2,000 Citrate	2.8	3.0	1,311	21	7.5	17.4	84.0	87.0
4	9	Rotary	500 Citrate	2.8[2]	5.5	461	50	9.8	10.3	—	—
5 a	9	Rotary	4,000 Citrate	7.0[3]	7.0	2,920	31	11.0	19.0	—	—
5 b	19	Rotary	2,000 Citrate	7.0[3]	7.0	1,195	55	8.9	24.2	—	—
5 c	18	Rotary	1,000 Citrate	7.0[3]	7.0	742	76	9.7	25.8	—	—
5 d	24	Rotary	500 Citrate	7.0[3]	7.0	495	81	10.7	34.6	—	—
5 e	21	Rotary	500 Citrate[4]	7.0	7.0	442	76	69.0	95.0	—	—
6	10	Tr. filt.	500 Citrate	3.5	5.5	454	29	8.1	56.4	—	—
7[5]	11	Tr. filt.	500 Citrate	7.0[6]	7.0	434	48	—	—	—	—

[1] In addition to nutrient. Unless noted, citric acid used in all experiments.
[2] pH adjusted with HCl.
[3] pH adjusted with NaOH.
[4] Ammonium citrate, as citrate.
[5] No settling time allowed for effluent.
[6] pH adjusted.

When citric acid was used to lower the pH, the break in per cent B.O.D. removal occurred between: 250 and 500 p.p.m. citrate loading; influent pH's of 4.2 and 3.5; and B.O.D.'s of 438 and 576 p.p.m. The break in the per cent B.O.D. removal, when the pH was adjusted to 7.0, occurred more gradually and was not noticeable until 1,000 p.p.m. of the citrate was added to produce a B.O.D. of 742 p.p.m. This showed that a 60 per cent B.O.D. removal could be attained with almost twice as much B.O.D. loading at pH 7 as at pH 3.5. The B.O.D. removals for both experiments with either low or neutral pH's ranged between 75 and 95 per cent prior to the break in the per cent B.O.D. removal.

The shock loading effects and the time required to reestablish equilibrium conditions were readily obtainable from these rotary tube experiments. The immediate reduction in per cent of B.O.D. removal, caused by changes in pH and organic loading, was very marked. Prior to the addition of citric acid to the influent, the slimes were receiving a nutrient solution at a pH of 7.0. The most severe decrease in the per cent B.O.D. removal occurred when citrate concentrations of 500 p.p.m. or more, and pH values lower than 3.5, were applied to nutrient acclimated slimes. When slimes were subjected to 500 and 2,000 p.p.m. of citrate, with resulting pH's of 3.5 to 2.8, the per cent B.O.D. removals dropped from 90 to 20 and 90 to 5, respectively. The time required to reestablish equilibrium under the new conditions of pH was about 18 days. At concentrations less than 500 p.p.m., and pH's higher than 3.5, recovery time was less than 5 days with negligible interference in efficiency. When the same citrate concentrations were continued but the pH adjusted to 7.0, the per cent of B.O.D. removal increased again and the time to reach an equilibrium was about three days.

There was no noticeable destructive effect on the rotary slimes until 250 p.p.m. of Igepal and 500 p.p.m. of

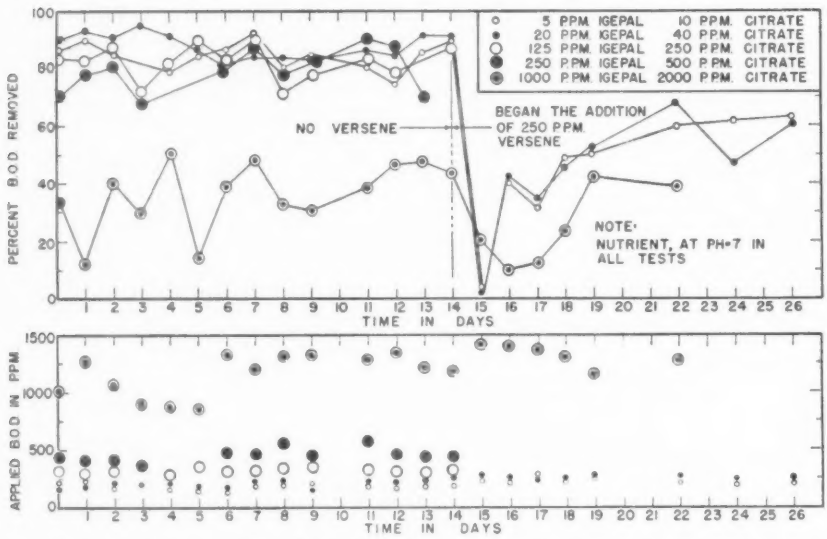
5 PPM. IGEPAL 10 PPM. CITRATE
20 PPM. IGEPAL 40 PPM. CITRATE
125 PPM. IGEPAL 250 PPM. CITRATE
250 PPM. IGEPAL 500 PPM. CITRATE
1000 PPM. IGEPAL 2000 PPM. CITRATE
NO VERSENE
BEGAN THE ADDITION OF 250 PPM. VERSENE
NOTE: NUTRIENT, AT PH=7 IN ALL TESTS
PERCENT B.O.D. REMOVED
TIME IN DAYS
APPLIED B.O.D. IN PPM
TIME IN DAYS

FIGURE 6.—Effect of synthetic laundry waste on the efficiency of rotating slime tubes.

citrate were applied. Combination of this amount of Igepal and citrate reduced the average B.O.D. removal of about 5 per cent as compared to citrate alone. Detailed results of the Igepal tests are presented in Figure 6. The major effect of Igepal on the rotary slimes was probably due to its frothing and detergent properties; for, when Igepal-containing wastes were applied to clean rotary tubes, the detergent ability of the Igepal caused the growing biological colonies to slip out of the tube. To overcome this problem, a slime growth had to be developed in the tubes prior to the addition of Igepal, or the Igepal concentration had to be temporarily reduced to about 50 p.p.m.

Another point of interest is that Igepal, which is an alkylphenylether of a polyethylene glycol, interfered with the Winkler test for the dissolved oxygen determination. The difficulty occurred when the iodide formed an Igepal-iodide precipitate. However, this detergent-iodide precipitate in the B.O.D. bottles was not too serious once it was discovered that the starch complex was stronger than the Igepal-iodide complex. As long as a representative sample, including precipitate, was taken for titration, the starch dissolved the Igepal-iodide complex and true titrations were obtainable.

It was ascertained that, after the application of 250 p.p.m. of Versene to a 2,000/1,000 p.p.m. citrate/Igepal solution, the B.O.D. removal was about 50 per cent as compared to 80 per cent prior to the addition of the Versene. The decreases in B.O.D. removals were caused by the inhibitory action of Versene and not by increases in oxidizable organic loadings. Versene does not have a B.O.D. The antagonistic and shock loading effects of Versene are illustrated in Figure 6. It was also observed that the concentration of Versene had to be reduced to about 50 p.p.m. or less before slimes would adhere to a clean surface of a rotary tube. If slimes were already attached to the surface, higher concentrations could be applied. This indicated that there was some competition between the surface-active bacterial cells and the surface-active chelates.

Exploratory experiments indicated that Tide and Rinso created a large organic load and reduced the per cent B.O.D. removal. Virtually all B.O.D.-producing substance in Rinso, and about 20 per cent in Tide, was available or metabolized in the 5-day B.O.D. tests. In the slime experiments, neither Tide nor Rinso in concentrations as low as 10 p.p.m. caused a decrease in B.O.D. removal efficiency. When the concentrations were increased as much as 100 p.p.m., however, some noticeable effects, such as B.O.D. reduction and decreased amounts of slime, were obtained.

Radioactivity Detention with Tubes

Isotopes were added to influent solutions at concentrations of 500 to 2,000 counts per minute per millimeter (10 per cent counting geometry). The detention of these tracer quantities of radioactivity was obtained by sampling and "counting" the evaporated influent and effluent samples. Carrier isotopes from the diluted stock played a negligible role in the competitive filter environment between stable and unstable isotopes. This desired effect was obtained by using a "high count" stock solution, which resulted in a very small amount of radioactive solution.

P^{32} was utilized as a metabolite by the organisms in rotating slimes, and the amount of P^{32} detained under various test conditions was approximately 10 to 30 per cent when the ratio of P^{32} to stable phosphorus was 1.58×10^{-8} to 27.5 p.p.m. This meant that approximately 10 to 30 per cent of the unstable phosphorus was used in metabolitic processes and was detained long enough to decay. The radioactive phosphorus is in competition with stable phosphorus; consequently, the uptake is dependent upon the ratio of the stable to the radioactive phosphorus ions. The extent to which phosphorus will be used is then also related to the nutrient available for cell growth and multiplication.

The detention of P^{32} was not affected by various synthetic laundry wastes and domestic settled sewage. Slimes which were fed on certain wastes—containing 500 p.p.m. citrate (pH 2.8) in one tube and 500 p.p.m. of ammonium citrate, as citrate (pH 7.0), in another—detained about 10 to 20 per cent of the applied P^{32}. The results are shown in Figure 7. There was little difference in the detention of P^{32} by sewage-fed slimes and those fed synthetic wastes. The detention of P^{32} by sewage slimes was 10 to 15 per cent for a flow of 7 l. per day, and 5 to 10 per cent for a flow of 16 l. per day. (Figure 8). As a result of these experiments, it was shown that the syn-

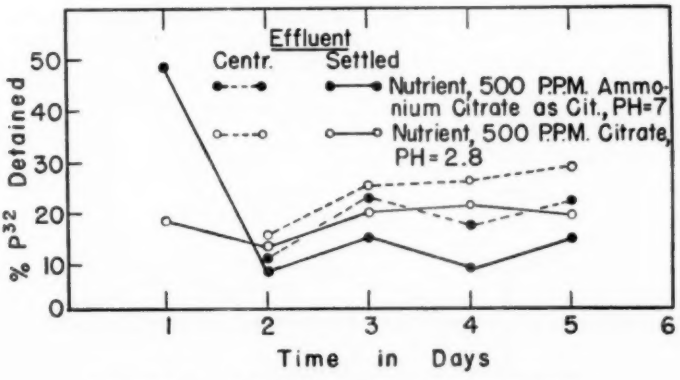

FIGURE 7.—P^{32} detention by slimes in rotating tubes.

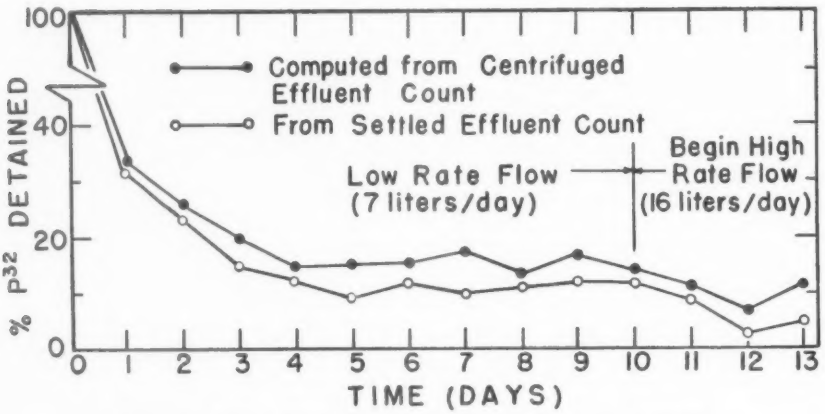

FIGURE 8.—P^{32} detention by sewage slimes in rotating tubes.

thetic laundry wastes provided conditions apparently similar to those of domestic sewage for the removal of P^{32}.

The removal of I^{131}, as iodide, was less than 10 per cent at equilibrium conditions when carrier-free iodine was used. Synthetic laundry wastes containing either 20 p.p.m. of Igepal and 500 p.p.m. of citrate, or 20 p.p.m. of Igepal and nutrient, all at a pH of 7.0, did not change the I^{131} detention characteristics of the slimes. There was, however, an important characteristic difference between synthetic wastes and domestic sewage; this difference was apparent on the first day of I^{131} application (Figure 9). The detention of I^{131} in the synthetic nutrient-fed slimes was about 10 to 20 per cent on the first day of application, whereas the detention by sewage slimes was about 40 to 60 per cent. The difference in I^{131} uptake was probably due to the additional silt and debris found in the sewage. Actually, bacterial cells would use minimum amounts of iodide and it is surprising that as much as 20 per

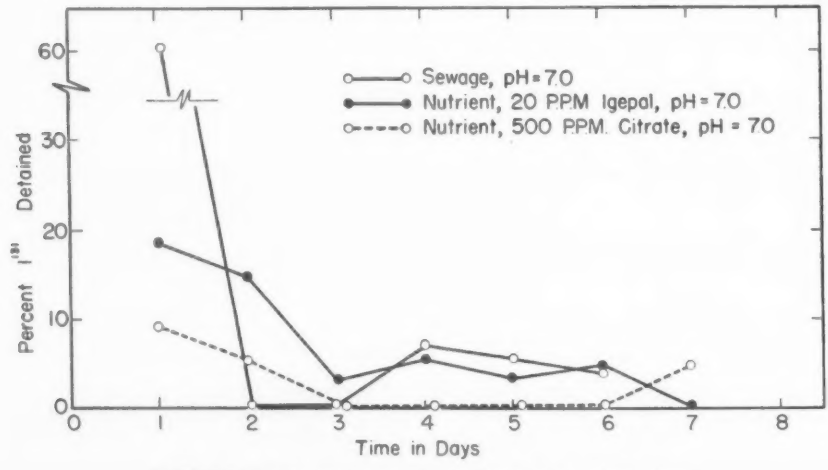

FIGURE 9.—Detention of I^{131} by slimes in rotating tubes.

cent was detained. Foreign materials, such as silver, in both synthetic wastes and sewage may have been in sufficient concentration to cause some precipitation and removal.

Three types of laundry wastes did not affect the removal of Sr^{89} by rotary tube slimes. The synthetic wastes were: (a) nutrient by itself, (b) nutrient containing 500 p.p.m. citrate and 250 p.p.m. Igepal, and (c) nutrient containing 50 p.p.m. Versene. All three wastes were adjusted to pH 7.0. The Sr^{89} detention, which was also the same for all these wastes, was about 15 per cent for the first day of sampling and 0 to 5 per cent thereafter. Much research is still required to predict with any degree of accuracy how Sr^{89} will behave in the presence of various complexing agents.

There was no real detention of Ru^{106} and Cs^{134} in the rotary slimes. The only perceptible detention occurred during the first few hours of application, when the contaminated liquid was displacing the original liquid in the slime structure. The wastes and the concentrations used for these experiments were identical with those described in the Sr^{89} experiments.

Detention of Ce^{144} by rotary slimes ranged between 30 and 50 per cent. As shown in Figure 10, there was no difference in the amount of Ce^{144} detained when treating two different types of waste. One waste was straight nutrient, whereas the other waste also contained 500 p.p.m. of citrate and 125 p.p.m. of Igepal, and both were at pH 7.0. There was no important difference in the amount of Ce^{144} detained during the first and subsequent days of application. This indicated that the manner in which Ce^{144} was removed was not dependent upon exchange or metabolic equilibrium conditions, as had been the case with P^{32}.

The external radiation on the outside of the plastic rotary tube was approximately 30 milliroentgens after applying for eight days a solution containing approximately 500 counts per minute per milliliter (10 per cent geometry) of Ce^{144}. These relatively high radiations were caused by the daughter decay product Pr^{144}, which has a half-life of 17.5 min., and decays with two betas and two gammas. The betas have energies of 3.07 and 0.041-million electron volts (MEV), while the two gammas have 0.135 and 1.25 MEV.

Waste Treatment with a Trickling Filter

The 8-ft. deep, 2 stage, 2½-in. diameter trickling filter showed no

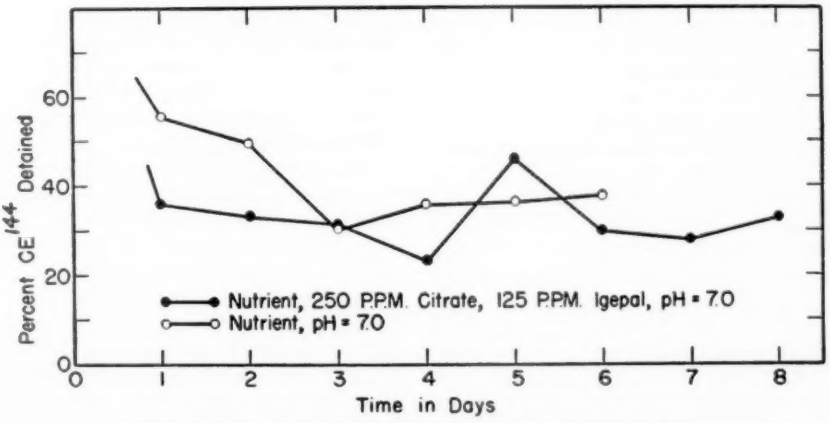

FIGURE 10.—Detention of Ce^{144} by slimes in rotating tubes.

marked improvement over a rotary slime tube in either B.O.D. reduction or isotope detention capacities, whereas it exhibited disadvantages in the time required to reach equilibrium. The physical and chemical conditions imposed on the trickling filter experiments were identical with those of the rotary tube experiments.

After about 25 days of conditioning, the trickling filter attained a 50 per cent B.O.D. removal when the pH was 3.5, and an 80 per cent removal when the pH was 7.0. The wastes in both bases contained 500 p.p.m. of citrate, which brought the applied B.O.D. up to about 400 p.p.m. The flow was also controlled at 7 l. per day, which was equivalent to about 6 m.g.a.d.

The range of radioactivity detention in the slimes of the trickling filter was 10 to 20, and 0 to 10 per cent, for P^{32} and I^{131}, respectively. The wastes in both cases contained 500 p.p.m. of citrate at a pH of 7.0. These detention percentages were about the same as those attained by slimes in rotary tubes. There was less than 5 per cent of I^{131} detained at either depth after equilibrium was reached on the fourth day of application. Throughout the test period, the first 4-ft. section of the trickling filter detained about 75 per cent of the total amount detained.

Discussion

The behavior of synthetic laundry wastes varied widely. Citrate, the most commonly used complexing agent in laundering, was readily utilized by organisms; and the organisms were adaptable to a wide range of pH. On the other hand, Versene, an important chelating agent, was a slime inhibitor. Such anionic detergents as Tide and Rinso (soap) and the nonionic detergent, Igepal, produced some deleterious effects on the slimes. Tide and Rinso both registered a high B.O.D. and were considerably more toxic to slimes than the Igepal. It was further found that Igepal and Versene were not attacked by biological forms, but caused an inhibition of growths as a result of their emulsifying and surface-active properties.

Citrates

Citrates are biologically oxidized and added to the organic loads in much the same manner as domestic sewage. If citric acid is included in the waste, the B.O.D. is increased and the pH is decreased. Therefore, laundry waste treatment design may be based largely upon the amount of citrate present. For example, the 5-day, 20° C. B.O.D. of a solution containing 2,000 p.p.m. citrate and nutrient (200 to 250 p.p.m.) was about 1,200 to 1,300 p.p.m. This 2,000-p.p.m. citrate concentration is equivalent to 87 lb. of B.O.D., and is approximately the amount of citrate load in the 8,000 gal. of laundry wastes discharged daily at Oak Ridge. The actual increase of organic load due to citrate is not, however, as serious a threat to biological treatment as might be expected. Each 500 p.p.m. of citrate doubled the B.O.D. load usually exhibited by an average domestic sewage (200 to 250 p.p.m.), and the per cent of B.O.D. removal affected by biological slimes was not reduced as drastically as it would be if the amount of organic matter in average domestic sewage were doubled.

It was also apparent that pH changes occasioned by the citrate were not a serious threat to laundry waste treatment. A waste which contained about 2,000 p.p.m. of critric acid, such as the Oak Ridge laundry effluent, would have a pH of about 2.8 and would require dilution with domestic sewage. This statement is based on the assumption that neutral detergents and laundering aids would be used. Dilution with water and synthetic nutrient was not very effective in increasing the pH until citrate concentration was less than 500 p.p.m., because of the buffering capacity of citric acid. At this citrate concentration, the effluent pH's of ro-

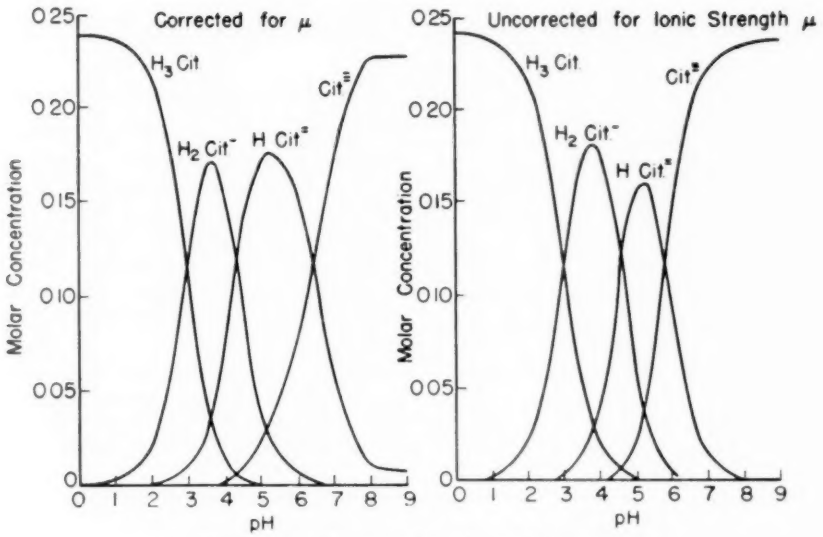

FIGURE 11.—Concentration of citrate ions *vs.* pH.

tary slime tubes had a tendency to approach 7.0 and the over-all B.O.D. reduction reached an asymptote. The tests made it obvious that low pH's due to citric acid were not as destructive to slimes as were inorganic acids. The concentration of 250 p.p.m. of citric acid, as citrate, could be utilized efficiently by slimes without decreasing the efficiency of a trickling filter; and the pH of the plant influent due to citric acid would be about 6.5. It was apparent that all of the readily oxidizable nutrient and citrate could be utilized by biological slimes as long as the pH remained above 6.5 and loadings were not excessive.

The influence of pH on the utilization of citrate by biological slimes is readily demonstrated by comparing the citrate ionization pattern with the B.O.D. removal pattern. The curves representing all of the various Cit^{---}, $HCit^{--}$, H_2Cit^{-}, H_3Cit are presented in Figure 11; complexed ion equilibrium conditions in the heterogeneous synthetic laundry wastes are presented in Figure 12. From these curves certain estimates may be made of B.O.D. removals from various concentrations of citric acid in a waste such as domestic sewage.

In order to base trickling filter design on citrate loading of rotary tubes, it was necessary to convert citrate B.O.D. values into "equivalent" trickling filter loading rates. Table III shows the converted B.O.D. loading rates as computed from the average applied B.O.D.'s. This conversion (from p.p.m. of applied B.O.D. for the rotary tubes, to pounds per acre per day for an "equivalent" trickling filter) was based on a hypothetical dosage rate of 8 m.g.a.d. over a 6-ft. deep trickling filter containing stone 2 in. in diameter. The dosage rate for a 6-ft. deep trickling filter would be about 4 m.g.a.d. if the conversion were based on stone 4 in. in diameter.

Taking into consideration the known B.O.D. output of 87.0 lb. per day of citrate waste from the Oak Ridge laundry, as well as the desired B.O.D. removal, the size of an "equivalent" trickling filter might then be estimated. For example, if rotary tubes affected a 60 per cent B.O.D. removal from a

waste containing 2,000 p.p.m. citrate at a pH of 7.0, it would be expected that a trickling filter receiving 87,000 lb. of B.O.D. per acre per day would also affect a B.O.D. removal of about 60 per cent. Based on the Oak Ridge laundry waste, an "equivalent" trickling filter 6-ft. deep, with hydraulic loading of 8 m.g.a.d. and having an area of 44 sq. ft., would be required to attain a B.O.D. removal of 60 per cent. This computed area is theoretical and must be increased to allow for plant inefficiency, effect of a slime-destroying detergent, and increased B.O.D. removal, if this is desired. The trickling filter area or the recirculation ratio must obviously be increased also if higher B.O.D. removals are required.

Effects of Detergents on Slime Growths

Experimental results showed that Igepal, Tide, and Rinso exhibited varied effects upon the operating characteristics of the treatment units. The surface active properties—that is, wetting, emulsifying, and frothing—were more important in some cases than their toxic or anti-bactericidal characteristics.

Igepal, a commonly used detergent in decontamination laundries, changed neither the pH nor the B.O.D. of the synthetic laundry wastes. This non-

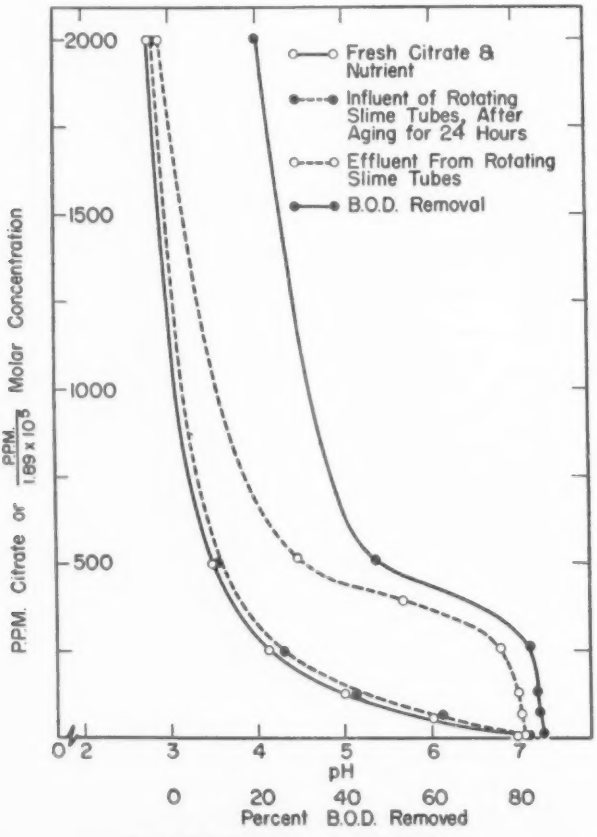

FIGURE 12.—Citrate characteristics.

TABLE III.—B.O.D. Loading Rates for Rotary Tube Operation

No.	Infl. pH	Citrate[1] (p.p.m.)	B.O.D. Applied			B.O.D. Rem. (%)
			(p.p.m.)	(lb./ac./day)	(lb./ac.-ft./day)	
1	7.0	0	258	17,200	2,860	85
2[2]	6.9	66	334	22,200	3,700	82
3[2]	4.8	125	338	22,500	3,760	83
4[2]	4.0	250	438	29,200	4,860	83
5[2]	3.5	500	576	38,400	6,400	44
6[2]	2.8	2,000	1,311	87,000	14,600	21
7[3]	7.0	4,000	2,920	195,000	33,000	31
8[3]	7.0	2,000	1,195	79,500	13,300	55
9[3]	7.0	1,000	742	49,500	8,200	76
10[3]	7.0	500	495	33,000	5,500	81
12[3]	2.8	500	461	31,000	5,100	55

[1] In addition to nutrient.
[2] Nutrient contributed about 260 p.p.m. of total B.O.D.
[3] Nutrient contributed about 200 p.p.m. of total B.O D.

ionic detergent was not attached by bacteria or yeast. In concentrations (of 1,000 p.p.m.) similar to those normally found at Oak Ridge, Igepal caused some slime inhibition in the rotary tubes. When the Oak Ridge detergent concentration was diluted with four times its volume in synthetic nutrient, there was no apparent decrease in B.O.D. removal by the slimes. The only serious treatment problem which Igepal exhibited toward slimes were those created by its emulsifying and wetting properties.

Igepal could be applied to a regular trickling filter with the expectation that the B.O.D. removal would be reduced about 5 per cent for each 250 p.p.m. of Igepal in the influent solution. The trickling filter stones would have to be coated with slimes prior to the addition of the Igepal-containing wastes; for, if Igepal precoats the surfaces of the stone, the slime growths would not have a suitable surface to which to adhere and grow.

The increase in oxidizable organic matter, as introduced with the addition of Tide or Rinso, would necessitate a larger treatment unit. Beside the increased organic loading effect, Tide and Rinso exhibited characteristics similar to those of Igepal.

Whether Igepal or other detergents should be recommended for use in a laundering process depends, among other things, upon (a) the capacity of the waste treatment plant, and (b) the assimilation capacity of the final diluting body of water. For example, in the laundering process it would be best to use a detergent that was oxidizable, provided a waste treatment plant was available for handling a large organic load. On the other hand, if the waste treatment plant was not designed to receive the extra organic loads supplied by an oxidizable detergent, it would be best to use Igepal in the laundering processes. If Igepal were used it would pass through the treatment unit; its toxic effects, if any, would be experienced in the diluting body of water. Such a method of detergent disposal would in reality depend upon the dispersion and dilution capacity of the receiving stream.

Radioactivity Removal

The following empirical data on radioactivity detention by bacteria and yeast were collected, and an attempt was made to seek out the predominant mechanisms by which a particular radioactive isotope was detained.

The participation of phosphorus in

biological phosphorylation processes has been well recognized. Therefore, the hypothesis that P^{32} could be detained by biological cells was never questioned (2); but it was necessary to determine quantitatively the amounts of removal under particular environmental conditions. Under certain conditions, when phosphorus is limiting, all the phosphorus will be removed from solution; if P^{32} is present, all the radioactivity will be removed initially by the growing cells. On the contrary, when phosphorus is not limiting, the P^{32} removal will depend upon the percentage of phosphorus utilized by growing organisms.

The percentage of P^{32} detained by the slimes in either a rotary tube or trickling filter over a prolonged period of time was sufficiently low to substantiate the evidence of uptake and release of phosphorus in the agitated batch-type experiments. Slime utilization of phosphorus was similar to the agitation experiments wherein new nutrient was added to a solution in which the nutrient was depleted and the P^{32} was released into the solution.

The experiments with phosphorus showed that continued phosphate fertilization of the trickling filter was not always necessary, even when a waste was deficient in phosphates. Initial slime-growing phases might require the addition of some phosphates; however, after equilibrium conditions were reached the phosphate budget in the filter was partially self-sustaining. Phosphates were continuously re-utilized by organisms which were constantly replacing the dead cells. The loss of phosphate occurred when viable cells were washed out of the filter unit or when periodic sloughing of slime occurred.

The mechanism of removal of Sr^{89} from solution by biological life was different from that exhibited by P^{32}. The detention of Sr^{89} by slimes in the rotary tubes partially substantiated the analysis obtained from the agitated flasks. The removal of Sr^{89} at pH 7.0 was very low (less than 15 per cent). This suggested that the pH and age of the bacterial cell was an important factor in the detention of Sr^{89}. Experiments using high and low pH values were not undertaken with the rotary tubes; but at pH 8.0, if the waste were adequately buffered, large amounts of Sr^{89} would probably be removed by each new crop of organisms.

Experiments with rotary tubes and trickling filters showed that there was some detention of I^{131} for one or two days. After an initial detention, however, no significant quantity of I^{131} was detained. Although it is known that iodides combine with some organic matter and possible exchange on some silts (3)(4), it must be concluded that the iodide ion in these experiments did not become attached in significant quantities to viable bacteria.

Ru^{106} and Cs^{134} were not detained by the rotary slime tubes, and only negligible amounts were taken up in other experiments. It is doubtful whether Ru^{106} could be removed in any appreciable amounts by biological processes. Probably the only manner in which Cs^{134} could be removed would be by the addition of silts.

A relatively high amount of Ce^{144} was removed by slimes in the rotary tubes. The rotary tubes effected a 50 per cent Ce^{144} detention, the mechanism of removal by organisms probably being due to the formation of insoluble compounds, which were precipitated and caught in the bacterial growths. Cerium forms several compounds that are insoluble in cold water. It can be assumed that a substantial reduction in the amount of cerium present in a liquid waste can be obtained by biological methods.

Conclusions

The following conclusions are based on the experimental results obtained in the biological treatment of synthetic laundry wastes contaminated with radioactive isotopes. Whenever possible the experimental data were in-

terpreted as being equivalent to data obtainable from a 6-ft. deep, standard-rate trickling filter.

Biological Oxidation of Laundry Wastes

1. Rotating slime tube experiments indicated that a trickling filter would remove about 70 to 80 per cent of the B.O.D. from a waste containing 500 p.p.m. citrate in addition to the usual amount of organic material found in an average domestic sewage. Such a waste would be produced when one part laundry waste is diluted with four parts sanitary sewage at Oak Ridge.

2. The B.O.D. removal by a trickling filter would be approximately 60 to 70 per cent when the applied domestic sewage contained 1,000 p.p.m. citrate and the pH was adjusted to 7.0.

3. A trickling filter would probably remove about 40 to 60 per cent of the applied B.O.D. if the waste, adjusted to pH 7.0, contained 2,000 p.p.m. of citrate in addition to at least the minimum amounts of domestic sewage solids or nutrients required to support biological growth. Such a waste would contain approximately 1,000 to 1,300 p.p.m. 5-day B.O.D.

4. Versene concentration of as much as 250 p.p.m. in an influent would probably cause a collapse in the slime structure and inadequate performance of a trickling filter.

5. A waste containing 1,000 p.p.m. of Igepal, when diluted by a factor of four with domestic sewage, would probably not interfere with trickling filter operations. The Igepal would cause some frothing but would most likely pass through the trickling filter bed without changing its chemical form.

6. Concentrations of 10 p.p.m. active ingredients of Tide or Rinso would not interfere with trickling filter slimes; however, as much as 100 p.p.m. would probably reduce the efficiency of a well-designed and operated plant as much as 15 per cent.

7. Although Igepal did not appreciably hinder waste treatment, its effects on aquatic life will need further investigation before it can be accepted as the laundering detergent least likely to cause eventual stream pollution.

Concentration of Radioactivity by Slimes

1. Negligible amounts of Sr^{89}, Cs^{134}, Ru^{106}, and I^{131} would be detained by the direct action of slimes at pH 7.0.

2. P^{32} detention by bacteria in a trickling filter for continued periods of time would be about 20 per cent and is dependent on the relative amounts of usable phosphorus and carbon in a waste.

3. About 30 to 50 per cent of the Ce^{144} would be removed by trickling filter slimes if the influent pH was 7.0.

4. If either Sr^{89} or Ce^{144} and domestic sewage were agitated in a batch treatment process until the pH became slightly alkaline during the biological growth phase, virtually all of the Sr^{89} and 85 per cent of the Ce^{144} would be adsorbed to cell structures.

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ECOLOGY OF LOS ANGELES–LONG BEACH HARBOR POLLUTION

An ecological study of the relationships of estuarine polychaetous annelids as pollution indicator organisms has been carried out in Los Angeles-Long Beach Harbors by D. J. Reish of the Department of Zoology and the Allan Hancock Foundation, University of Southern California. The study was supported by a research grant from the National Institutes of Health, USPHS.

A progress report covering the period September 1953 to March 1954 showed the following:

Present oxygen levels are less than in August 1951, slightly less than in September 1951, and greater than for the three following months. The water transparency was about the same for both periods. At 23 of the 55 stations no visible evidence of pollution was noted, the substratum usually being a fine gray mud, supporting a rich and varied fauna, the polychaetous annelids being the most abundant group of organisms.

Evidence of some pollution was found at 32 stations, the substratum usually being covered by a black sulfide mud. At these stations fewer animal species were found, with 3 being characterized by complete absence of animal life. Dredging in the East Basin of Los Angeles Harbor in the spring of 1953 apparently removed the pollutants accumulated on the bottom so that this area now supports a richer fauna.

Field study of the larval migrations of these marine invertebrates into polluted zones shows promise in determining if the species can invade polluted areas, and if so at what stage or stages in their life histories they are being killed. Preliminary results indicate that some species found only in the cleaner portions of the harbors do migrate into the polluted area, but apparently are killed at the time of settling or shortly thereafter.

Stream Pollution

ANALYSIS OF A STREAM'S CAPACITY FOR ASSIMILATING POLLUTION

By M. A. Churchill

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It is generally recognized that the use of a stream for ultimate disposal of waterborne wastes is both reasonable and necessary. However, disposal of excessive or inadequately treated wastes limits use of the stream for other purposes which may be more beneficial to the region. Streams have tremendous capacity for self-purification and economy dictates that as much —but no more—of the stream's natural capacity for absorbing pollution should be used as is consistent with all other uses of the water.

The ultimate purpose of all stream sanitation activities is to establish and maintain a reasonable and economic balance between man's many uses of streams which do not lower water quality, and his use of streams for waste disposal. One of the prerequisites for establishing this balance is the determination of the stream's capacity for absorbing pollution. This paper presents a method for determining quantitative relationships between organic waste loads put into a stream and the resulting dissolved oxygen depletion.

A number of workers in the field have previously developed methods for determining the relationship of dissolved oxygen to pollution loads. The first and still the basic method was devised by Streeter and Phelps (1). Velz (2) and Thomas (3) published modifications of the original approach. A number of others have proposed procedures for solving the basic equations of Streeter and Phelps and for evaluating the "constants" involved. LeBosquet and Tsivoglou (4) published a method considered to be a significant contribution. The last two authors show how their method is a special application of the Streeter-Phelps equations at the location of the low point on the dissolved oxygen (D.O.) sag.

Although the Streeter-Phelps approach to the problem has been the accepted "standard" for many years, the application of its equations involves a number of practical difficulties, chief among them being: (a) the high cost and difficulty of determining the time of flow between successive sampling stations along the D.O. sag curve; (b) a large field and laboratory staff (and a fairly large laboratory) must be available to collect and analyze the numerous samples collected during the intensive sampling period required; and (c) the fact that the so-called constants k_1 and k_2 are not really constants, but must be re-evaluated by additional extensive observations on the same reach of river for changed conditions of pollution loading and river discharge.

In the method of analysis developed herein, time of water travel is not needed, the necessary samples can be collected and analyzed routinely by a small staff, and no long-term B.O.D. determinations are required. Office

calculations are relatively simple and, if the suggested statistical procedures are employed, the dependability of the relationships developed can be evaluated.

An example of the method, as applied to a specific stream section, is given.

Method Applied to Specific Problem

Basic observational data for this paper were supplied to the Tennessee Valley Authority by an industrial concern hereafter referred to as Industrial Plant. This source of data was selected because the data are fairly extensive and because the plant is rather well isolated from other sources of pollution, thus making presentation of the method uncomplicated. In addition, the data illustrate the type of information any forward-looking industry can obtain with reasonable cost concerning the effects of its own wastes on receiving streams.

Industrial Plant takes its process water from Plant River and also discharges its waste waters into this same stream. A short distance downstream Plant River flows into Main River (Figure 1).

Basic Data

During 1944 and 1945 personnel of Industrial Plant collected field information and water samples routinely from a number of sampling stations on Plant River, Branch River, and Main River.

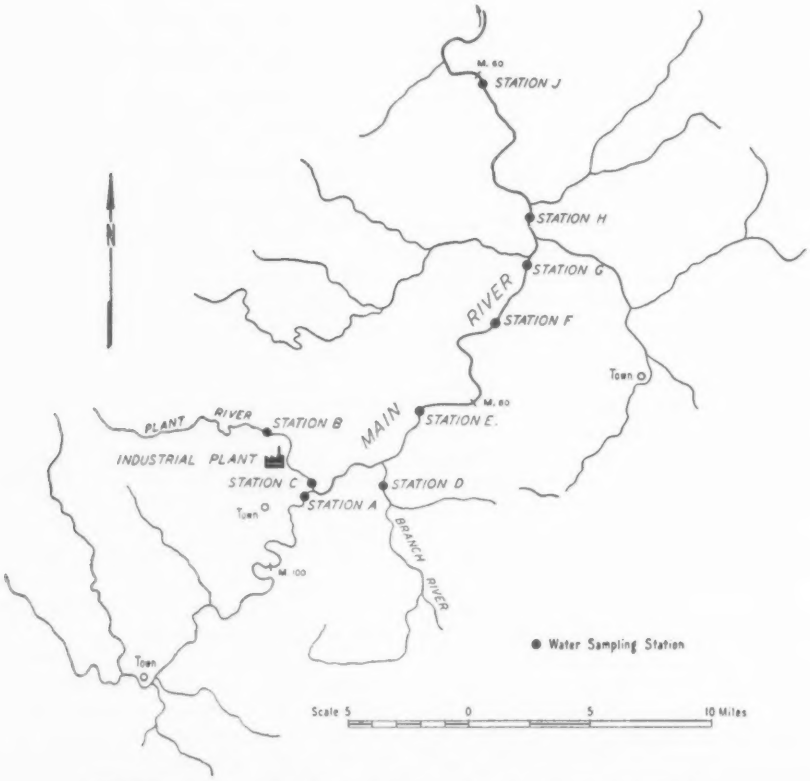

FIGURE 1.—Location of sampling stations in illustrative problem.

TABLE I.—Basic Data from River Samples

Date	Station B, Plant River Above Pollution, Mile 2.0					Station C, Plant River Below Pollution, Mile 0.4[1]					Station D, Branch River, Mile 1.2				
	Temp. (°C.)	pH	D.O. (p.p.m.)	B.O.D. (p.p.m.)	Disch. (c.f.s.)	Temp. (°C.)	pH	D.O. (p.p.m.)	B.O.D. (p.p.m.)	Disch. (c.f.s.)	Temp. (°C.)	pH	D.O. (p.p.m.)	B.O.D. (p.p.m.)	Disch. (c.f.s.)
5/24/44	18.6	6.7	10.2	0	154	19.1	9.5	7.3	54.5	153	—	—	—	—	—
5/25/44	18.8	6.7	10.6	1	147	19.3	10.1	7.3	50.5	147	—	—	—	—	—
5/26/44	17.7	6.7	10.5	0	197	18.0	9.5	8.2	42.5	198	—	—	—	—	—
5/30/44	19.0	6.7	10.5	0	141	19.6	9.7	6.9	57.5	141	—	—	—	—	—
5/31/44	—	6.8	10.5	0	132	—	9.7	6.1	52.5	131	—	—	—	—	—
6/2/44	18.0	6.9	10.5	0	127	19.0	9.5	7.3	36.0	127	—	—	—	—	—
6/9/44	—	—	—	—	—	18.0	9.5	9.0	43.5	131	17.2	6.9	10.4	1	160
6/16/44	21.7	7.1	10.4	0	117	22.1	9.3	5.6	78.5	116	19.6	7.0	10.0	1	169
6/19/44	—	—	—	—	—	23.2	—	4.9	85	99	20.8	—	10.0	1	139
6/23/44	—	—	—	—	—	21.2	—	5.4	84	88	20.2	—	9.8	1	99
7/1/44	18.0	7.0	10.9	0	77.5	21.3	9.8	3.0	137	77	20.0	7.0	10.1	2	94
7/5/44[2]	15.2	6.7	11.3	0	71.3	16.2	6.7	10.6	2.0	71	15.5	6.7	10.5	1	51
7/15/44	18.2	6.8	10.7	0	96	19.9	9.5	8.2	34	96	19.9	6.8	10.0	1	105
7/22/44	17.0	6.9	11.4	0	60.5	23.3	9.5	3.5	161	60	19.7	7.1	10.7	1	101
7/26/44	19.2	6.9	11.4	0	56	22.2	9.4	4.1	105	56	19.8	6.9	11.1	2	85
7/27/44	26.0	7.1	10.2	0	53	—	9.4	3.1	161	53	21.5	7.3	10.8	2	84
7/28/44	—	—	—	—	—	25.0	9.4	5.6	35	51	21.5	6.9	10.9	3	108
7/29/44	19.3	7.1	11.2	0	65	21.9	10.0	1.7	142	65	19.5	7.0	10.6	1	85
8/2/44	18.8	6.8	11.0	1	94	20.8	9.3	8.8	36	94	20.8	6.9	10.6	1	108
8/19/44	—	—	—	—	—	22.3	9.8	3.4	144	56	19.6	7.0	11.4	1	67
8/26/44	—	—	—	—	—	22.0	9.9	2.1	142	45	17.0	6.8	8.9	1	43
9/2/44	20.2	7.0	8.5	0	50	24.5	10.2	1.0	192	50	20.8	6.9	8.1	1	—
9/20/44	17.5	7.2	9.1	1	62	23.5	9.8	3.8	83	62	19.0	7.2	8.6	1	—
9/30/44	—	—	—	—	—	19.8	9.3	7.7	21	201	18.9	6.8	8.4	2	310
3/20/45	—	—	—	—	—	18.0	9.4	6.7	40	108	—	—	—	—	—
5/31/45	—	—	—	—	—	21.0	9.0	4.9	42	94	19.0	—	8.4	1	139
6/13/45	—	—	—	—	—	22.0	9.6	3.9	57	70	17.5	7.0	8.7	1	101
7/3/45	20.0	7.1	8.5	0	60	24.0	10.1	0.0	106	60	20.5	7.0	8.3	1	101
7/5/45[2]	20.0	6.5	7.5	1	74	20.0	6.8	7.7	2	74	20.5	6.6	7.7	1	171
7/5/50[2]	18.0	7.2	8.7	1.3	—	—	—	—	—	—	—	—	—	—	—

TABLE I.—*Continued*

Date	Station A, Main River, Mile 92.1[1]					Station E, Main River, Mile 83.7[1]					Station F, Main River, Mile 73.3[1]				
	Temp. (°C.)	pH	D.O. (p.p.m.)	B.O.D. (p.p.m.)	Disch. (c.f.s.)	Temp. (°C.)	pH	D.O. (p.p.m.)	B.O.D. (p.p.m.)	Disch. (c.f.s.)	Temp. (°C.)	pH	D.O. (p.p.m.)	B.O.D. (p.p.m.)	Disch. (c.f.s.)
5/24/44	19.2	7.2	8.5	1	486	18.6	7.1	6.1	6	865	—	—	—	—	—
5/25/44	18.0	6.7	9.2	2	529	18.0	7.0	7.1	5	978	—	—	—	—	—
5/26/44	19.0	6.8	8.8	1	560	18.2	7.0	6.7	7	1,015	—	—	—	—	—
5/30/44	18.5	6.7	9.0	2	822	18.5	7.0	6.8	5	995	—	—	—	—	—
5/31/44	—	6.8	8.4	2	538	18.5	7.1	6.4	7	850	—	—	—	—	—
6/2/44	19.0	6.8	8.6	2	512	18.7	7.1	7.0	4	795	—	—	—	—	—
6/9/44	17.9	7.1	9.2	2	422	17.8	7.5	7.0	8	753	—	—	—	—	—
6/16/44	21.4	7.0	8.5	3	381	20.7	7.1	5.3	7	710	—	—	—	—	—
6/19/44	22.1	—	9.0	2	339	22.5	—	5.0	5	606	23.1	—	3.2	3	651
6/23/44	20.1	—	8.7	2	320	21.0	—	4.3	10	557	21.6	—	3.4	6	563
7/1/44	19.5	7.0	8.8	2	437	20.5	7.0	4.5	9	592	21.1	6.9	1.9	7	528
7/5/44[2]	17.3	6.8	9.5	2	313	17.5	6.7	8.5	2	458	18.5	6.6	7.1	2	515
7/15/44	20.1	6.8	9.0	2	393	20.3	7.1	5.3	9	688	21.1	6.8	3.5	5	717
7/22/44	21.2	6.9	8.9	8[3]	286	20.5	7.1	3.6	13	428	20.3	6.8	2.0	7	500
7/26/44	20.2	6.9	9.1	2	258	21.0	7.0	2.8	11	354	22.0	6.8	1.8	7	402
7/27/44	23.0	6.9	8.5	2	242	22.8	7.1	1.1	9	330	22.3	6.7	1.4	7	393
7/28/44	23.8	6.8	8.6	2	252	23.0	7.0	1.3	19	343	23.3	6.7	1.2	9	379
7/29/44	20.7	6.8	9.0	3	283	21.8	6.9	1.3	17	383	22.6	6.7	1.4	7	413
8/2/44	19.1	6.6	9.5	2	485	19.5	6.9	5.9	8	778	20.0	6.7	4.2	4	957
8/19/44	19.7	6.9	9.4	1	228	20.8	7.1	2.6	9	344	21.8	6.9	1.0	10	427
8/26/44	18.8	6.9	7.3	1	182	19.8	7.2	0.8	14	266	20.2	6.9	0.7	9	340
9/2/44	22.0	6.4	6.8	1	269	22.0	7.1	2.3	7	441	22.2	6.7	1.1	7	526
9/20/44	20.5	7.0	6.9	2	260	20.0	7.2	2.6	8	445	19.5	6.9	1.3	7	502
9/30/44	18.5	6.5	6.9	3	1,020[3]	18.8	6.8	6.2	7	1,640[3]	18.8	6.7	2.1	9	1,530[3]
5/31/45	19.5	6.7	7.2	1	393	20.0	7.5	5.0	7	648	20.0	6.5	2.2	6	660
6/13/45	21.0	7.0	7.1	2	300	21.0	7.0	2.3	8	458	22.0	6.9	1.2	4	488
7/3/45	21.5	6.8	7.1	2	269	22.0	6.7	0.5	15	420	23.0	6 7	0.0[3]	17[3]	488
7/5/45[2]	20.5	6.4	7.3	2	220	20.0	—	5.4	1	528	21.5	6.5	3.8	2	500
7/5/50[2]	20.1	6.8	7.6	3	400	20.4	7.1	7.2	2.2	672	21.1	6.7	6.1	2	730
7/5/52[2]	20.8	6.9	7.6	1	275	20.5	6.6	6.2	1.9	456	21.6	6.6	4.7	2	490

TABLE I.—*Continued*

Date	Station G, Main River, Mile 70.8[1]					Station H, Main River, Mile 67.5[1]					Station J, Main River, Mile 60.6[1]				
	Temp. (°C.)	pH	D.O. (p.p.m.)	B.O.D. (p.p.m.)	Disch. (c.f.s.)	Temp. (°C.)	pH	D.O. (p.p.m.)	B.O.D. (p.p.m.)	Disch. (c.f.s.)	Temp. (°C.)	pH	D.O. (p.p.m.)	B.O.D. (p.p.m.)	Disch. (c.f.s.)
6/19/44	23.0	—	3.8	6	711	23.0	—	5.9	5	1,095	23.2	—	7.1	3	1,200
6/23/44	22.0	—	3.0	4	618	22.5	—	5.1	3.5	850	23.8	—	7.2	2.5	925
7/1/44	22.0	6.8	2.5	6	557	22.1	6.8	4.9	4	764	23.5	7.0	6.5	3	825
7/5/44[2]	19.0	6.6	7.7	2	547	19.0	6.7	7.7	2	729	19.6	6.9	9.7	2	796
7/15/44	21.0	6.8	4.3	5	787	21.2	6.8	6.6	3	1,010	23.4	6.9	6.6	3	1,115
7/22/44	20.8	6.8	2.1	6	532	19.9	7.1	4.8	4	714	20.8	7.0	6.8	3	796
7/26/44	22.4	6.8	1.7	7	432	22.4	6.8	4.0	4	569	23.5	6.9	7.7	3	637
7/27/44	22.0	6.7	1.8	6	419	21.9	6.8	3.6	4	557	22.2	7.0	6.6	3	601
7/28/44	23.2	6.8	1.6	6	402	22.9	6.8	3.3	5	532	23.5	6.9	6.7	4	575
7/29/44	23.0	6.7	2.4	5	428	23.0	6.8	4.2	3	602	24.0	7.0	7.0	5	655
8/2/44	20.4	6.7	4.8	4	1,015	21.0	6.7	5.7	4	1,085	22.0	6.8	7.5	4	1,275
8/19/44	22.0	6.9	2.3	10	450	22.1	6.9	3.5	6	557	23.1	7.0	6.9	2	627
8/26/44	20.2	7.0	1.2	7	359	20.0	6.9	3.0	6	—	20.8	7.1	5.2	3	495
9/2/44	22.8	6.8	1.4	5	594	22.9	6.8	2.9	4	754	23.2	7.0	4.9	3	831
9/20/44	19.5	6.9	1.5	7	545	19.5	6.9	3.5	4	685	19.5	7.0	5.1	3	763
9/30/44	19.0	6.7	2.3	8	1,470[3]	18.8	6.7	4.4	6	2,350[3]	18.8	6.6	4.8	—	2,560[3]
5/31/45	20.5	6.6	3.8	4	678	21.0	6.7	4.1	3	910	22.0	6.4	8.9[3]	2	1,030
6/13/45	22.5	6.8	1.4	3	540	22.0	6.8	3.5	3	730	23.0	7.0	5.7	2	867
7/3/45	23.5	6.7	0.2	10	540	23.5	7.7	2.7	4	569	24.0	5.9	4.8	4	760
7/5/45[2]	22.0	—	3.8	3	540	21.0	6.5	5.2	3	870	22.0	6.7	6.2	2	1,020
7/5/50[2]	21.3	6.8	5.9	2	800	20.8	6.8	5.7	2.5	1,190	21.5	6.8	6.6	4	1,440
7/5/52[2]	21.5	6.5	4.9	2	520	21.2	6.6	5.7	2	680	21.2	6.7	6.4	1	785

Station	Mean B.O.D. Load		Mean D.O. Drop	
	(lb./day)	95% Conf. Lim.	(lb./day)	95% Conf. Lim.
C	36,120	30,970–41,270	—	—
A	3,780	3,040–4,520	—	—
E	26,500	23,780–29,220	11,710	10,750–12,670
F	17,620	15,730–19,510	17,590	15,820–19,360
G	17,190	14,560–19,820	17,600	15,990–19,210
H	15,880	13,450–18,310	15,850	14,700–17,000
J	13,550	11,080–16,020	9,660	6,900–12,420

[2] Plant shut down. [3] Value not used.

All available results on temperature, pH, dissolved oxygen, and B.O.D. determinations made during the summer months when water temperatures exceeded 17° C., at the stations shown in Figure 1, are included in Table I. Stream discharges based on records from three gaging stations on the Main River and from gaging stations on five local tributaries were supplied by the Hydraulic Data Branch of the Tennessee Valley Authority.

Variable B.O.D. Load

The mill is located on Plant River, a small tributary of Main River. Above the mill there is practically no pollution, inasmuch as the stream flows out of a very lightly inhabited area. Grab samples collected from Plant River below the mill show the B.O.D. load in terms of pounds per day to be extremely variable. The samples are truly random, according to mill officials, and were taken to obtain a picture of the pollutional effect of mill operations on the waste-receiving stream. The normal operation of the mill results in variable loadings on the stream on an hour-to-hour and day-to-day basis. The results of B.O.D. grab samples (Table I) on Plant River below the mill showed the maximum observed load to be at the rate of 57,000 lb. per day and the minimum 9,600 lb. per day. Obviously, grab samples under such conditions must be interpreted carefully in order that the results will not be misleading. With the aid of statistical procedures, however, the grab sample values can be used to yield dependable results when analyzed by the method proposed herein.

Inasmuch as statistical procedures are used considerably in this paper, all of the procedures are shown in detail in the appendix for the sampling data at Station E, which is on the Main River at river mile 83.7.

The effect of the pollution load on D.O. levels in the river is shown quite clearly by the observed D.O. profiles of Figure 2.

The B.O.D. load in the Main River above the mouth of the Plant River is very low (Station A, Table I). The only sizable organic load imposed on the Main River in the 30-mi. reach below the mouth of the Plant River is that from the mill.

D.O. Drop vs. B.O.D. Loading

It is common knowledge that the reason for the existence of a D.O. sag in a stream is the organic pollution load put into the water upstream. A basic relationship must exist, therefore, between the size of the load, the stream flow or dilution available, and the degree of D.O. depletion. This is the relationship sought by this study.

It is evident that the size of the load and the stream flow can be combined into a B.O.D. concentration unit, such as B.O.D. in pounds per day per c.f.s. of stream flow. A basic relation should exist at each sampling station along the D.O. sag, therefore, between the decrease, or drop, in D.O. concentration in p.p.m. (from above pollution to each sampling station along the sag) and B.O.D. in pounds per day per c.f.s. of stream flow. The B.O.D. found in a sample at a station below pollution represents the remainder of the pollution that has moved downstream with the water, depleting the D.O. along the way.

There are many other factors entering into the general relationship which tend to produce variations in observed results when these factors are not taken into account. In this approach to the problem, however, the secondary influences are omitted from the basic relationship. The effects on the accuracy of the results which arise from the omission of these modifying factors are discussed later in the paper.

Inasmuch as Station A is on the Main River just upstream from the Plant River where the pollution enters, this point was used as a base in com-

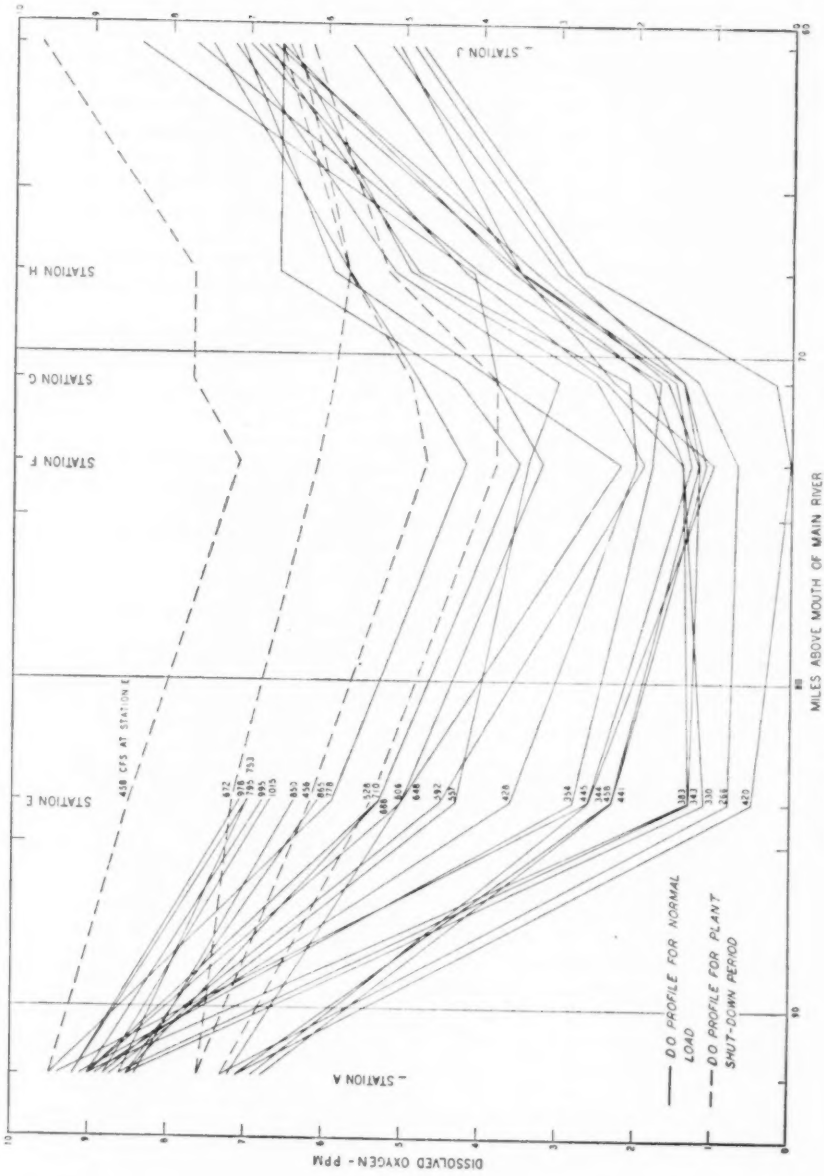

FIGURE 2.—Observed D.O. profiles on Main River.

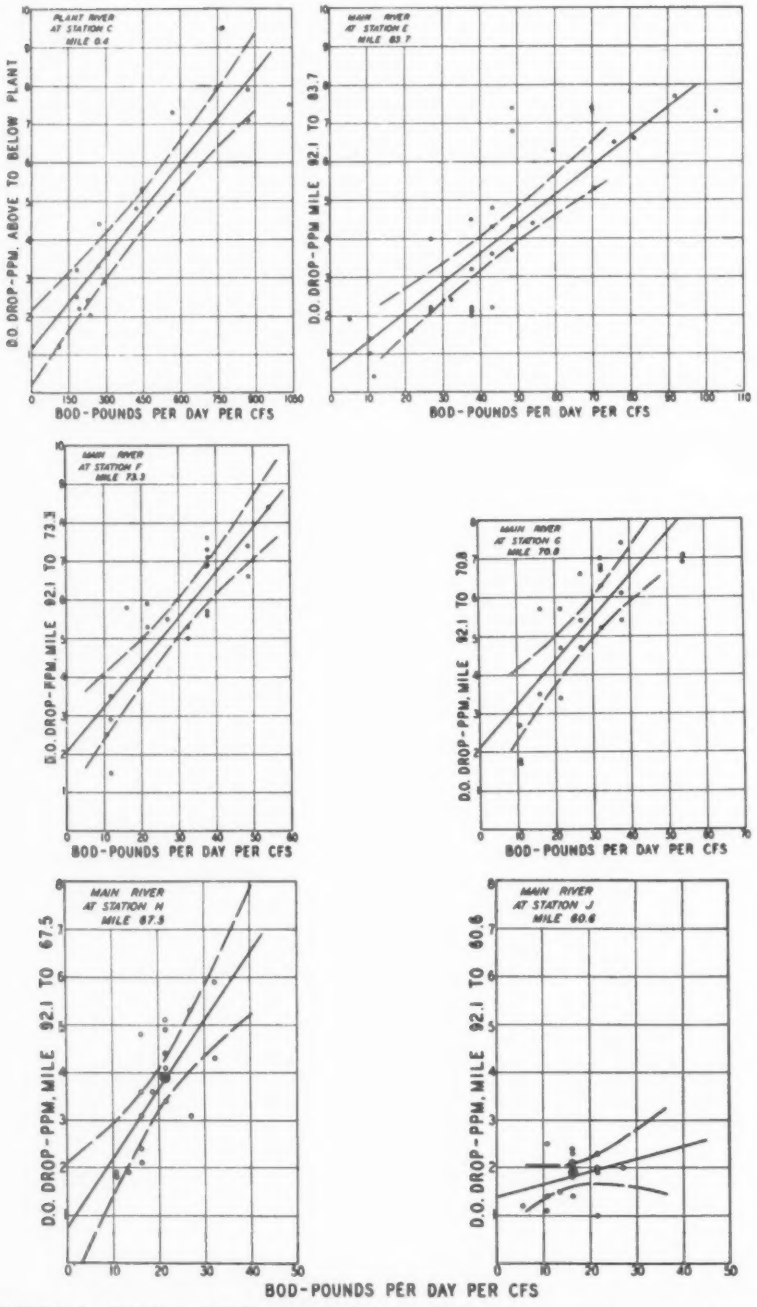
PLANT RIVER AT STATION C MILE 0.4
D.O. DROP-PPM. ABOVE TO BELOW PLANT
BOD-POUNDS PER DAY PER CFS
MAIN RIVER AT STATION E MILE 83.7
D.O. DROP-PPM MILE 92.1 TO 83.7
BOD-POUNDS PER DAY PER CFS
MAIN RIVER AT STATION F MILE 73.3
D.O. DROP-PPM MILE 92.1 TO 73.3
BOD-POUNDS PER DAY PER CFS
MAIN RIVER AT STATION G MILE 70.8
D.O. DROP-PPM. MILE 92.1 TO 70.8
BOD-POUNDS PER DAY PER CFS
MAIN RIVER AT STATION H MILE 67.5
D.O. DROP-PPM. MILE 92.1 TO 67.5
MAIN RIVER AT STATION J MILE 60.6
D.O. DROP-PPM. MILE 92.1 TO 60.6
BOD-POUNDS PER DAY PER CFS

FIGURE 3.—Relation of D.O. drop to B.O.D. Solid line represents mean relationship; dashed lines, 95 per cent confidence limits.

puting the drop in D.O. values on each sampling date. These values for D.O. drop, 5-day B.O.D. values, and stream discharges at each downstream station on the Main River were used to plot the relationships shown in Figure 3. The relationship shown for the Plant River is based on the drop in D.O. concentration from above to below the source of pollution.

The solid line for each station was fitted to the data by the method of least squares. (See Appendix: such a fitting is not essential to the method, but obviously more accurate results can be thus obtained.) Since D.O. is the dependent variable in the relationship, the regressions shown were computed in the normal way; that is, the regressions are for y upon x, and not x upon y. There is an important difference. Obviously, the fitted line cannot be expected to define the absolutely true relationship of these variables at a station, since only a limited number of samples were collected. On the other hand, it is the best approximation of the true relationship that can be obtained from the available data. The curved dashed lines were computed by statistical methods (see Appendix) and represent the 95 per cent confidence limits of the true relationship. In other words, the odds are 19 to 1 that the true relationship lies within the limits outlined by the dashed lines. These probability limits are very useful in that they provide a guide to the dependability of the relationships.

The values for 5-day B.O.D. were computed by

$$\text{Pounds per day} = \text{p.p.m.} \times \text{c.f.s. of stream flow} \times 5.4,$$

from which it is evident that values of B.O.D. in pounds per day per c.f.s. can be obtained by multiplying p.p.m. B.O.D. by 5.4. Thus, the relationships shown in Figure 3 can be thought of as D.O. drop in p.p.m. *versus* B.O.D. in p.p.m. times a constant.

Admittedly, there is considerable scatter to the data for each of the relationships shown by Figure 3. However, the 95 per cent confidence limits shown for each regression line indicate that if the regression lines are used to predict D.O. drop values from known B.O.D. load conditions, the error from the true mean value will be rather small in terms of p.p.m. D.O. When the variable nature of the load is considered, with varying degrees of longitudinal mixing in the river, together with the fact that no attempt has been made to adjust the data for water temperature effect (all data for temperatures of 17° C. or over were used), for algal effects on D.O., or for times of water travel, then the degree of scatter is understandable.

Based on values of the correlation coefficient (see Appendix) for each regression line, the degree of correlation, as shown in the following, is quite good for all stations except Station J, in spite of the factors tending to produce scatter:

Station	Correlation Coefficient, r
C	0.92
E	0.85
F	0.86
G	0.79
H	0.73
J	0.27

If all the observed points for any sampling station on Figure 3 formed a perfectly straight line the coefficient of correlation would be 1.00 for that location. If they scattered in a random or "buckshot" fashion the coefficient would be near 0.0. When the coefficient is 1.00 and a value for either of the two variables is known, the value of the other can be predicted perfectly. When the coefficient is near zero, a knowledge of one of the variables is of little value in predicting the value of the other.

It should be noted that the correlation coefficient decreases in a downstream direction. This indicates that progressively more and more of the scatter of the data in a downstream

direction is due to effects of secondary influences. As is discussed later in this paper, the influence on D.O. of organic material on the bottom of the stream, in relation to the total D.O. drop, increases in a downstream direction and this influence is the major reason for the progressive decrease in correlation. At Station J this is particularly true. In addition, Station J is located well downstream from the low point of the D.O. sag and thus the observed individual D.O. drop values are all relatively small, B.O.D. loads are also quite small, and as a result there is a limited range of data from which to compute a correlation coefficient.

Direct observations have indicated the almost complete absence of algae in the heavily polluted section of the river. Furthermore, frequent observations during a 24-hr. period at one station failed to show any change in D.O. concentrations in passing from daylight to darkness, and *vice versa*, that could be attributed to algal activity.

Effects of algae on D.O. are present in the Main River above Plant River, and at the tributary stations, as evidenced by the numerous supersaturation values shown for these locations in Table I.

The quantity of D.O. added to a relatively clear stream by algae normally varies considerably throughout the day during the warm months of the year. Since pollution, both domestic and industrial, clouds the receiving waters to some extent, it thus reduces the extent of light penetration. This, of course, reduces photosynthesis and the production of oxygen by algae. Observations of D.O. about dawn are the least influenced by algae and, of course, usually show the lowest actual concentration. This fact is well-known and is often used in evaluating critical conditions.

Progressive Reduction in B.O.D. Load

The river, of course, is very effective in reducing the B.O.D. load imposed upon it as the water flows downstream. To determine the size of the imposed load during the period of observations, the mean load in terms of pounds per day of 5-day B.O.D. was computed for each station (Table I).

It might be expected that there would be a correlation, at each station below the Plant River, of the B.O.D. load in pounds per day with stream flow. Plots of these data, however, reveal only a "buckshot" pattern at Stations E, F, and G. At Stations H and J there is some correlation, apparently due to the fact that at these locations, well downstream from the low point of the D.O. sag, B.O.D. values have been reduced to rather low and uniform concentrations by natural

TABLE II.—Natural and Added Pollution Loads

Station	River Flow[1] (c.f.s.)	B.O.D. Load (lb./day)		
		Natural, at 1 p.p.m.	Measured, Mean	Added
Station A	370	2,000	3,780	1,780
Plant River[2]	96	520	36,120	35,600
Below Plant River	—	—	—	37,380
Station E	592	3,200	26,500	23,300
Station F	534	2,980	17,620	14,640
Station G	572	3,090	17,190	14,100
Station H	772	4,170	15,880	11,710
Station J	858	4,630	13,550	8,920

[1] Average on sampling days.
[2] Below Industrial Plant.

purification and longitudinal mixing upstream. Under these conditions an increase in flow results in an increase in total B.O.D. load at the lower two stations.

The low B.O.D. values of unpolluted tributaries (such as the Plant River above Industrial Plant, and Branch River) indicate that the B.O.D. in the Main River would normally be about 1 p.p.m. if no other pollution were added.

The quantity of man-made pollution existing at each station is computed by subtracting the natural pollution load of 1 p.p.m. B.O.D. from the mean load observed during the study (Table II). The values in the last column of Table II are plotted against river miles in Figure 4. The progressive downstream reduction in added load is quite evident.

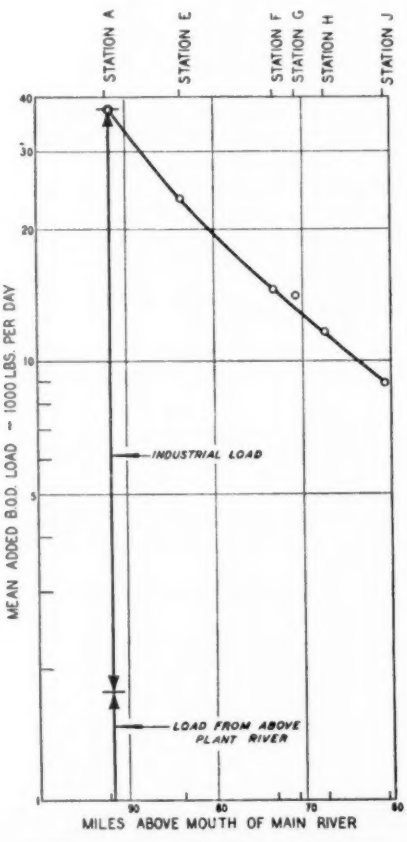

FIGURE 4.—Progressive downstream reduction in B.O.D. load.

Normal Increase in Flow of River

From a plot of the individual river flows at each sampling station against the flow at a selected base station (Station E) the normal increase in flow from station to station, at various levels of flow, was determined. If such data are not available, flow increases in proportion to drainage area (assuming no regulation by dams) are reasonably accurate. The normal progressive downstream increase in stream flow is used, as indicated in Table III, to compute D.O. profiles for various stream flow levels.

Application of Method

Normal Load Conditions

All the data needed to use the method for normal load conditions have now been developed. Table III illustrates the step-wise procedures to be followed and the results obtained when the normal load is applied to the stream at several stream flow levels. The computed D.O. profiles are shown in Figure 5.

In computing the values in Table III, the added load from above the Plant River is assumed unchanged. In any situation where such is not the case, proper adjustments can be made.

The lowest observed D.O. value in the Main River at the station (Station A) above the Plant River is about 7 p.p.m. This value is used, therefore, as the initial D.O. value in Table III because its use will yield the lowest D.O. values downstream.

Effects of Organic Bottom Material

As shown by Figure 3, the vertical axis intercepts of the regression lines indicate a significant D.O. drop even when there is no load discharged from

Industrial Plant. The sag exists because of the B.O.D. of material on the bottom of the river. Supporting data for this statement are available from the observations of July 5 in 1944, 1945, 1950, and 1952. Each year the plant is shut down for a few days during early July. During these particular years the plant was shut down on July 3, July 3, July 1, and July 3, respectively. The samples were collected on July 5 just prior to beginning operations again. During the shut-down, the river below the plant has a chance to flush itself of practically all suspended and dissolved B.O.D., as indicated by the extremely low B.O.D. values on each July 5 at each station (Table I).

The low B.O.D. values on July 5 show only nominal suspended and dissolved pollution, particularly at Stations E, F, and G. At the lower end of the reach under observation, flushing action was not so complete and at least part of the D.O. drop observed on July 5 was due to suspended and dissolved pollution originating before

TABLE III.—D.O. Profiles for Normal B.O.D. Load and Various Flows at Station E

Location	Discharge (c.f.s.)	B.O.D. Load (lb./day)				D.O. Drop[4] (p.p.m.)	D.O.[4] (p.p.m.)
		Natural[1]	Added[2]	Total	(per c.f.s.)		
(*a*) 210 C.F.S. AT STATION E							
Station A	150	810	1,780	—	—	0.0	7.0
From Plant R.	30	160	35,600	—	—	—	—
Below Plant R.	180	970	37,380	38,350	—	—	—
Station E	210	1,130	23,300	24,430	116	9±	0
Station F	280	1,510	14,640	16,150	58	8.8	0
Station G	310	1,670	14,100	15,770	51	7.8	0
Station H	410	2,210	11,710	13,920	34	5.7	1.3
Station J	450	2,430	8,920	11,350	25	2.0	5.0
(*b*) 400 C.F.S. AT STATION E							
Station A	260	1,400	1,780	—	—	0.0	7.0
From Plant R.	60	320	35,600	—	—	—	—
Below Plant R.	320	1,720	37,380	39,100	—	—	—
Station E	400	2,160	23,300	25,460	64	5.4	1.6
Station F	440	2,380	14,640	17,020	39	6.6	0.4
Station G	480	2,590	14,100	16,690	35	6.0	1.0
Station H	620	3,350	11,710	15,060	24	4.2	2.8
Station J	700	3,780	8,920	12,700	18	1.9	5.1
(*c*) 600 C.F.S. AT STATION E							
Station A	340	1,840	1,780	—	—	0.0	7.0
From Plant R.	90	490	35,600	—	—	—	—
Below Plant R.	430	2,330	37,380	39,710	—	—	—
Station E	600	3,240	23,300	26,540	44	3.9	3.1
Station F	620	3,350	14,640	17,990	29	5.4	1.6
Station G	700	3,780	14,100	17,880	26	5.0	2.0
Station H	880	4,750	11,710	16,460	19	3.5	3.5
Station J	980	5,290	8,920	14,210	14	1.8	5.2

[1] Computed for assumed natural B.O.D. of 1.0 p.p.m.
[2] From Table II.
[3] From regression lines of Figure 3.
[4] Obtained by subtracting values of D.O. drop from 7.0 p.p.m.

TABLE III.—*Continued*

Location	Discharge (c.f.s.)	B.O.D. Load (lb./day)				D.O. Drop[3] (p.p.m.)	D.O.[4] (p.p.m.)
		Natural[1]	Added[2]	Total	(per c.f.s.)		
(*d*) 800 C.F.S. AT STATION E							
Station A	450	2,430	1,780	—	—	0.0	7.0
From Plant R.	110	590	35,600	—	—	—	—
Below Plant R.	560	3,020	37,380	40,400	—	—	—
Station E	800	4,320	23,300	27,620	34	3.1	3.9
Station F	840	4,530	14,640	19,170	23	4.7	2.3
Station G	1,000	5,400	14,100	19,500	20	4.3	2.7
Station H	1,180	6,370	11,710	18,080	15	2.9	4.1
Station J	1,340	7,230	8,920	16,150	12	1.7	5.3
(*e*) 1,000 C.F.S. AT STATION E							
Station A	560	3,020	1,780	—	—	0.0	7.0
From Plant R.	140	750	35,600	—	—	—	—
Below Plant R.	700	3,770	37,380	41,150	—	—	—
Station E	1,000	5,400	23,300	28,700	29	2.7	4.3
Station F	1,050	5,670	14,640	20,310	19	4.3	2.7
Station G	1,250	6,750	14,100	20,850	17	4.0	3.0
Station H	1,470	7,930	11,710	19,640	13	2.6	4.4
Station J	1,680	9,060	8,920	17,980	11	1.7	5.3

shut-down. The sag observed during these shut-down periods is due primarily to material on the bottom of the river, but also to some extent to upstream residual pollution, pollution not flushed out of eddies, and during 1950 and 1952 to a very small load from a portion of Industrial Plant not shut down completely.

The D.O. drop was computed in

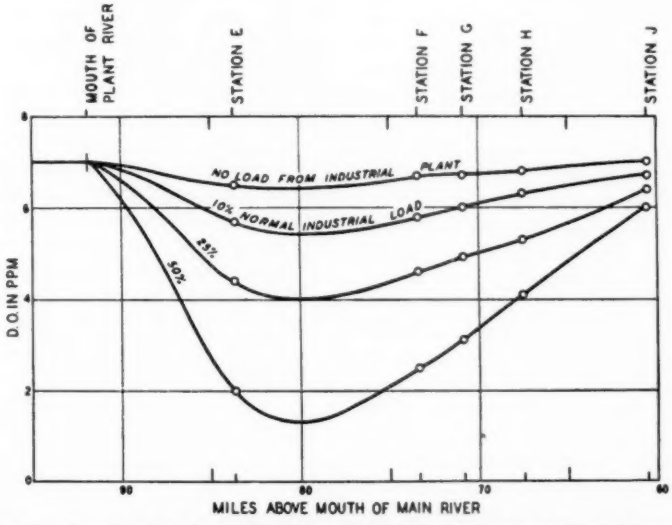

FIGURE 5.—Computed D.O. profiles for normal B.O.D. load and various stream flows.

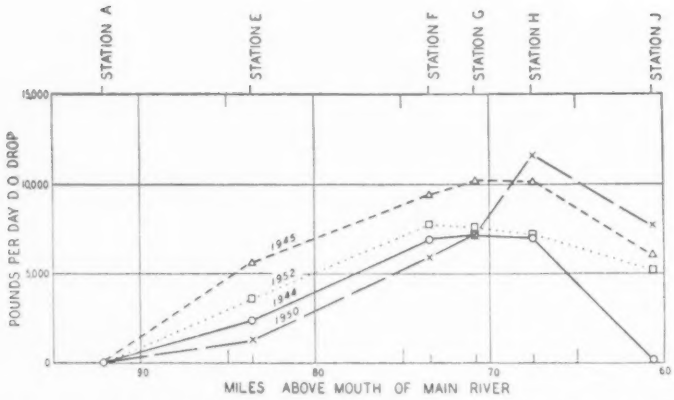

FIGURE 6.—Pounds per day D.O. drop observed during periods of plant shut-down

pounds per day from data observed on July 5 of the several years (Figure 6). The magnitude of the D.O. drop during shut-down periods as shown by Figure 6 is better appreciated when it is realized that the mean D.O. drop to Station F during normal plant operation is only 17,590 lb. per day. In other words, the drop during shut-down periods is in the neighborhood of one-third to one-half the total drop in that reach of river which includes the lowest point on the oxygen sag curve. Since observations of D.O., etc., were made some two days after the time the plant was actually shut down, bottom effects are undoubtedly more pronounced during normal operation, inasmuch as the B.O.D. exertion is greatest when the top layer of organic material on the bottom of the river is the freshest.

Obviously, bottom deposits and slime growths are not stable or constant in amount. A scouring flood would remove them. However, the low-flow period of the summer is usually preceded by a period during which the flows trend downward. It is during this period that the deposits build up. The deposits should not be thought of as purely sludge banks, because much of the bottom undoubtedly is coated with adapted bacterial slimes, similar to the ones on a trickling filter, together with organic material removed from the water by the slimes. Thus, bottom effects would exist even if all the "settleable solids" were to be removed by treatment of the plant wastes.

If no man-made pollution were added to the river, the natural B.O.D. throughout the reach would be about 1 p.p.m. Under these conditions there would obviously be no D.O. sag. If under 1944–5 load conditions no bottom deposits existed, the sag would be due to dissolved and suspended B.O.D. only. Then the regression lines of Figure 3 for each station would intercept the horizontal axis at a B.O.D. value of about 5.4, because this is the abscissa value corresponding to 1 p.p.m. B.O.D.

The vertical distance from this point on the horizontal axis to the fitted regression line for each station is an approximation of the quantitative effect of bottom material during the summer months in terms of p.p.m. D.O. drop at low stream flows. The following values for bottom effects were read from Figure 3:

Station	Approx. Bottom Effects, in Terms of D.O. Drop (p.p.m.)
E	0.9
F	2.7
G	2.7
H	1.5
J	1.5

It must be emphasized that these bottom effects are not at all constant throughout the summer. The preceding values can be only approximations applicable to low flows during the low-flow season. Some years the effects may be more, other years less, depending on preceding flow and load conditions.

Reduced-Load Conditions

For reduced-load conditions, the simple and frank assumption is made that if the load were reduced to any given fraction of its normal value and maintained for some time at that reduced level, the quantitative effects of bottom material on D.O. drop would ultimately be reduced in the same proportion.

A study, by probability methods, of the minimum daily flow during each summer shows that, based on the 32 years of stream-flow record at Station E, a minimum daily summer flow as low as 210 c.f.s. can be expected once in 10 years at this location.

Table IV and Figure 7 show the effect on D.O. profiles of several load reductions at Industrial Plant. In these computations the once-in-10-years low stream flow was used. The drop correction value indicated in Table IV is the proportionate reduction in D.O. drop that would occur in the D.O. drops shown by Figure 3, if the imposed loads were reduced as indicated in the headings of Table IV.

General Discussion of Method

It is believed that the proposed method can be useful in analyzing grab-sample data collected on many streams. Since a few grab samples can be very misleading, a reasonable number of such samples for a range of stream-flow conditions is necessary for acceptable accuracy of results.

As with any method of analysis, extrapolation very far beyond the range of observed data is dangerous.

By using the grab-sample technique, with this method of analysis, a small field force can collect sufficient data for analysis from a number of stream reaches during the warm-weather pe-

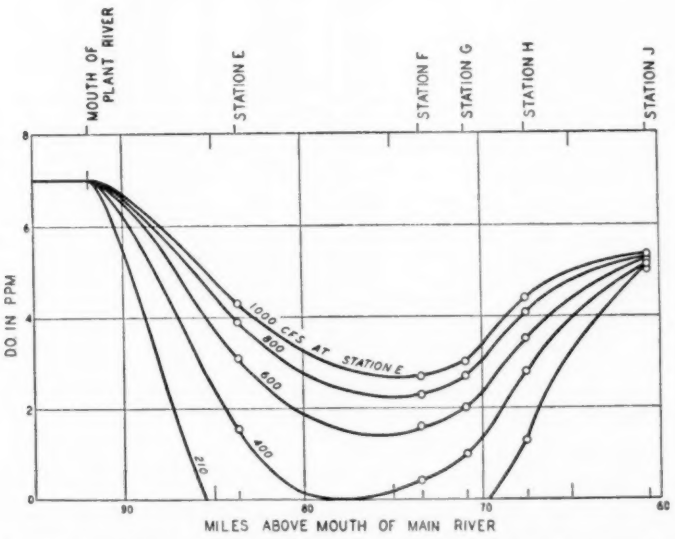

FIGURE 7.—Computed D.O. profiles for reduced B.O.D. loads and 10-year minimum stream flow.

TABLE IV.—D.O. Profile for Various Industrial Plant Waste Loads and 210-c.f.s. Flow at Station E

Location	Discharge (c.f.s.)	B.O.D. Load (lb./day)				D.O. Drop[2] (p.p.m.)	D.O. Correction[3] (p.p.m.)	D.O.[4] (p.p.m.)
		Natural	Added[1]	Total	(per c.f.s.)			
(a) 50 Per Cent Normal Load from Industrial Plant								
Station A	150	810	1,780	—	—	—	—	7.0
From Plant R.	30	160	17,800	—	—	—	—	—
Below Plant R.	180	970	19,580	20,550	—	—	—	—
Station E	210	1,130	12,200	13,330	64	5.4	−0.4	2.0
Station F	280	1,510	7,670	9,180	33	5.9	−1.4	2.5
Station G	310	1,670	7,390	9,060	29	5.3	−1.4	3.1
Station H	410	2,210	6,130	8,340	20	3.7	−0.8	4.1
Station J	450	2,430	4,670	7,100	16	1.8	−0.8	6.0
(b) 25 Per Cent Normal Load from Industrial Plant								
Station A	150	810	1,780	—	—	—	—	7.0
From Plant R.	30	160	8,900	—	—	—	—	—
Below Plant R.	180	970	10,680	11,650	—	—	—	—
Station E	210	1,130	6,660	7,790	37	3.3	−0.7	4.4
Station F	280	1,510	4,180	5,690	20	4.4	−2.0	4.6
Station G	310	1,670	4,030	5,700	18	4.1	−2.0	4.9
Station H	410	2,210	3,350	5,560	14	2.8	−1.1	5.3
Station J	450	2,430	2,550	4,980	11	1.7	−1.1	6.4
(c) 10 Per Cent Normal Load from Industrial Plant								
Station A	150	810	1,780	—	—	—	—	7.0
From Plant R.	30	160	3,560	—	—	—	—	—
Below Plant R.	180	970	5,340	6,310	—	—	—	—
Station E	210	1,130	3,330	4,460	21	2.1	−0.8	5.7
Station F	280	1,510	2,090	3,600	13	3.6	−2.4	5.8
Station G	310	1,670	2,010	3,680	12	3.4	−2.4	6.0
Station H	410	2,210	1,670	3,880	9	2.0	−1.3	6.3
Station J	450	2,430	1,270	3,700	8	1.6	−1.3	6.7
(d) No Load from Industrial Plant								
Station A	150	810	1,780	—	—	—	—	7.0
From Plant R.	30	160	0	—	—	—	—	—
Below Plant R.	180	970	1,780	2,750	—	—	—	—
Station E	210	1,130	1,110	2,240	11	1.4	−0.9	6.5
Station F	280	1,510	700	2,210	8	3.0	−2.7	6.7
Station G	310	1,670	670	2,340	8	3.0	−2.7	6.7
Station H	410	2,210	560	2,770	7	1.7	−1.5	6.8
Station J	450	2,430	420	2,850	6	1.5	−1.5	7.0

[1] Values for Sta. E and downstream computed to maintain same ratio of reduced station load to reduced load below Plant River as existed for measured added loads shown in last column of Table II.

[2] From regression lines of Figure 3.

[3] To be applied to D.O. drop values for reduced effect of bottom deposits; reduced effects proportional to load reductions.

[4] Obtained by reducing D.O. drop by D.O. correction and subtracting from 7.0 p.p.m.

riod of one year. By such a procedure, a relatively small staff, operating on a small budget, can evaluate the pollution assimilative capacity of many streams in a short period of time.

Acknowledgments

The writer is grateful to the management of Industrial Plant for permission to use the basic observed data. Inclusion of the July 5 results for plant shut-down periods makes these observations particularly valuable.

Acknowledgment is due R. A. Buckingham, Public Health Engineer, Stream Sanitation Section, TVA, for assistance in computations, critical review of text, and for many valuable suggestions.

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APPENDIX.—STATISTICAL TREATMENT OF STATION E BASIC DATA

Fitting of Regression Line of Figure 3 by Method of Least Squares

Date	D.O. (p.p.m.)		y, D.O. Drop (p.p.m.)	y^2	B.O.D., Sta. E (p.p.m.)	x, B.O.D. in (lb./day/c.f.s.)	x^2	xy
	Sta. A	Sta. E						
5/24/44	8.5	6.1	2.4	5.76	6	32.4	1,049.76	77.76
5/25/44	9.2	7.1	2.1	4.41	5	27.0	729.00	56.70
5/26/44	8.8	6.7	2.1	4.41	7	37.8	1,428.84	79.38
5/30/44	9.0	6.8	2.2	4.84	5	27.0	729.00	59.40
5/31/44	8.4	6.4	2.0	4.00	7	37.8	1,428.84	75.60
6/2/44	8.6	7.0	1.6	2.56	4	21.6	466.56	34.56
6/9/44	9.2	7.0	2.2	4.84	8	43.2	1,866.24	95.04
6/16/44	8.5	5.3	3.2	10.24	7	37.8	1,428.84	120.96
6/19/44	9.0	5.0	4.0	16.00	5	27.0	729.00	108.00
6/23/44	8.7	4.3	4.4	19.36	10	54.0	2,916.00	237.60
7/1/44	8.8	4.5	4.3	18.49	9	48.6	2,361.96	208.98
7/5/44	9.5	8.5	1.0	1.00	2	10.8	116.64	10.80
7/15/44	9.0	5.3	3.7	13.69	9	48.6	2,361.96	179.82
7/22/44	8.9	3.6	5.3	28.09	13	70.2	4,928.04	372.06
7/26/44	9.1	2.8	6.3	39.69	11	59.4	3,528.36	374.22
7/27/44	8.5	1.1	7.4	54.76	9	48.6	2,361.96	359.64
7/28/44	8.6	1.3	7.3	53.29	19	102.6	10,526.76	748.98
7/29/44	9.0	1.3	7.7	59.29	17	91.8	8,427.24	706.86
8/2/44	9.5	5.9	3.6	12.96	8	43.2	1,866.24	155.52
8/19/44	9.4	2.6	6.8	46.24	9	48.6	2,361.96	330.48
8/26/44	7.3	0.8	6.5	42.25	14	75.6	5,715.36	491.40
9/2/44	6.8	2.3	4.5	20.25	7	37.8	1,428.84	170.10
9/20/44	6.9	2.6	4.3	18.49	8	43.2	1,866.24	185.76
5/31/45	7.2	5.0	2.2	4.84	7	37.8	1,428.84	83.16
6/13/45	7.1	2.3	4.8	23.04	8	43.2	1,866.24	207.36
7/3/45	7.1	0.5	6.6	43.56	15	81.0	6,561.00	534.60
7/5/45	7.3	5.4	1.9	3.61	1	5.4	29.16	10.26
7/5/50	7.6	7.2	0.4	.16	2.2	11.9	141.61	4.76
7/5/52	7.6	6.2	1.4	1.96	1.9	10.3	106.09	14.42
Total			112.2	562.08		1,264.2	70,756.58	6,094.18

$$\frac{(\Sigma y)^2}{n} = \frac{112.2^2}{29} = 434.10 \qquad \frac{(\Sigma x)^2}{n} = \frac{1{,}264.2^2}{29} = 55{,}110.40$$

$$\frac{\Sigma x\,\Sigma y}{n} = \frac{1264.2 \times 112.2}{29} = 4{,}891.15$$

$$D = \Sigma(x^2) - \frac{(\Sigma x)^2}{n} = 70{,}756.58 - 55{,}110.40 = 15{,}646.18$$

$$S = \Sigma(y^2) - \frac{(\Sigma y)^2}{n} = 562.08 - 434.10 = 127.98$$

$$N = \Sigma(x\,y) - \frac{\Sigma x\,\Sigma y}{n} = 6{,}094.18 - 4{,}891.15 = 1{,}203.03$$

$$b_{y.x} = \frac{N}{D} = \frac{1{,}203.03}{15{,}646.18} = 0.0769$$

$$a = \bar{y} - b\bar{x} = 3.869 - 0.0769 \times 43.59 = 0.517$$

Equation of fitted regression: $y = 0.517 + 0.0769\,x$

95 Per Cent Confidence Limits of Average Value of y for a Given Value of x

The Standard Error of Prediction of an average value of y for a given value of x is given by

$$\text{S.E.} = s_{y.x}\sqrt{\frac{1}{n} + \frac{(x - \bar{x})^2}{D}}$$

$$s_{y.x} = \sqrt{\frac{S - \frac{N^2}{D}}{n-2}} = \sqrt{\frac{127.98 - \frac{1{,}203.03^2}{15{,}646.18}}{27}} = 1.146$$

When x = the mean value of x, or 43.59,

$$\text{S.E.} = 1.146\sqrt{\frac{1}{29} + 0} = 0.213.$$

Student's $t_{0.05}$ for 27, or $n - 2$, degrees of freedom = 2.052.

S.E. $\times\ t_{0.05} = 0.213 \times 2.052 = 0.437.$

95% C.L. of y for x of 43.59 = 3.869 ± 0.437 p.p.m.

When x = 53.59 and 33.59,

$$\text{S.E.} = 1.146\sqrt{\frac{1}{29} + \frac{100}{15{,}646.18}} = 0.231.$$

S.E. $\times\ t_{0.05} = 0.231 \times 2.052 = 0.474.$

95% C.L. of y for x of 53.59 = 4.647 ± 0.474 p.p.m.

95% C.L. of y for x of 33.59 = 3.100 ± 0.474 p.p.m.

For other selected values of x, the 95% C.L. are computed similarly.

Correlation Coefficient

$$r = \frac{N}{\sqrt{D\,S}} = \frac{1{,}203.03}{\sqrt{15{,}646.18 \times 127.98}} = 0.85.$$

THE OPERATOR'S CORNER

CONDUCTED BY HERBERT P. ORLAND

ELECTRODE PUMP CONTROL

BY G. J. COPPA

Superintendent, Sewage Treatment Plant, Concord, Calif.

Originally the pumping station at the Concord, Calif., sewage treatment plant was designed with three pumps (two of 500-g.p.m. and one of 700-g.p.m. capacity) operated by an electrode control. The system worked reasonably well, except that it gave a pulsating or uneven flow through the clarifier because of the inherent limitations in the set-up. With six relays and transfer plugs any pump could be set to start on one of six levels. But all the pumps would stop at the low electrode. This meant that if the flow was 1,300 g.p.m., for example, a 500-g.p.m. unit would start up, then another 500-g.p.m. unit to make a total of 1,000 g.p.m., then the 700-g.p.m. unit to total 1,700 g.p.m. All would pump to lower the wet well level, then all would shut off and the cycle would be repeated.

The plant's consulting engineer, E. Ogden Driggs, of the firm of Bates & Trotter, Berkeley, Calif., had worked out a system of "following the flow" at another plant by means of float-controlled mercoid switches. It was decided, therefore, to try a similar system using the relays already installed. As a result of a plant enlargement then being carried out, four pumps (capacities of 700, 1,000 1,300, and 2,000 g.p.m.) were involved.

New Electrode Assembly

The old electrodes had hung from a holder on flexible wires. This arrangement was unsatisfactory, as rags would become entangled and there was a constant maintenance problem.

New electrodes were built up, therefore, by carefully insulating ½-in. galvanized pipe with "Scotch" waterproof plastic electrical tape, using the 2-in. width. Brass plugs soldered watertight were used to close the pipe ends. The pipes were then mounted 8 in. apart between 1-in. by 2-in. insulating strips and hung about 1 ft. from the wet well wall on a frame. After the wires were attached with brass screws, more tape was used to insulate and cover the wires and all but the lower tips of the pipe electrodes. This is expected to control corrosion from hydrogen sulfide gas. Figure 1 shows the electrode assembly.

Pumping Program

The relays were then rewired as shown in Figure 2. Transfer plugs are available for changing the hook-up, but the present pumping program is as given in Table I. Under this program if the incoming flow is, say, 1,200 g.p.m., the pumps will deliver first 700 g.p.m., then 1,300 g.p.m., and alternate between the two rates, but at no time will there be a complete shutdown.

The only bad spot in the program is at a flow between 2,000 and 3,000 g.p.m., as the pumps will deliver 2,000, then 3,000, then 1,300 g.p.m. before starting the cycle again at 2,000 g.p.m.

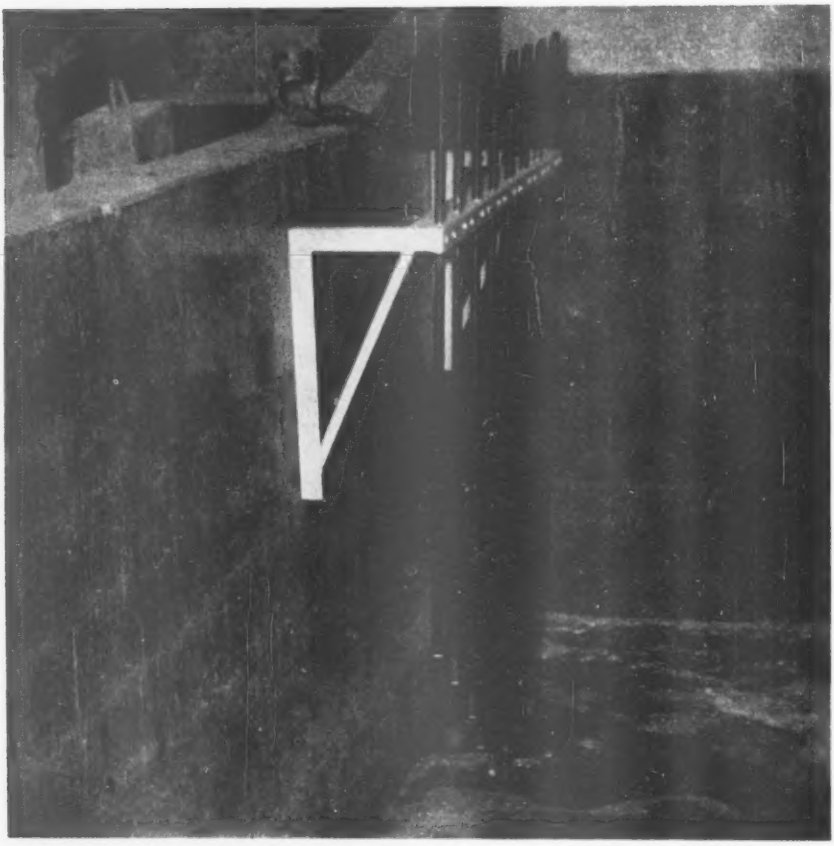


FIGURE 1.—Shop-made electrode assembly in sewage wet well gives "follow-the-flow" pump operation for smoother clarifier flow.

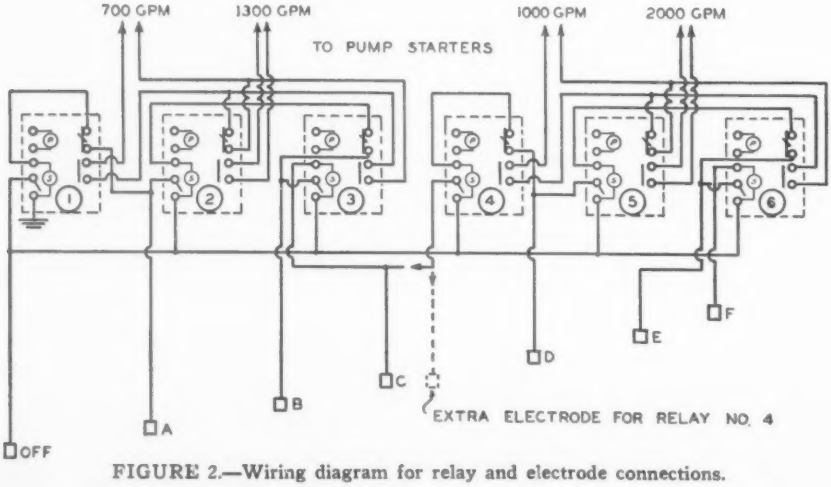


FIGURE 2.—Wiring diagram for relay and electrode connections.

TABLE I.—Pumping Program at Concord, Calif., Sewage Treatment Plant as Controlled by Wet Well Liquid Level

Flow (g.p.m.)	Elev. (ft.)	Program Designation	Action[1]	Pumps[1] Running
(a) On Rising Water Level				
0	0.8	—	—	—
700	1.5	A	2 on	2
1,300	2.0	B	3 on, 2 off	3
2,000	2.5	C	2 on	2 and 3
3,000	3.0	D	1 on	1,2, and 3
4,000	3.5	E	4 on, 1 off	2,3, and 4
5,000	4.0	F	1 on	1,2,3, and 4
(b) On Falling Water Level				
4,000	3.5	E	1 off	2,3, and 4
3,000	3.0	D	1 on, 4 off	1,2, and 3
1,300	2.0	B	1 and 2 off	3
700	1.5	A	2 on, 3 off	2
0	0.8	—	2 off	—

[1] Pumps 1,2,3, and 4 have capacities of 1,000, 700, 1,300, and 2,000 g.p.m., respectively.

This break in the program results from an unwillingness on the part of all concerned to pull out the 7 conductors presently in the conduit and pull 8 conductors back in. By using 8 electrodes and connecting as shown by the dotted line instead of to electrode C (Figure 2), the program changes would be the same for both rising and falling water levels. Any influent flow is handled between two of the program "stations" so that the pumps keep "following the flow" and give a more uniform feed to the clarifiers. This is believed to induce better sedimentation in the clarifiers.

The relay and electrode control system has the advantages of being positive and dependable. If the pump program were controlled from a single float, any malfunction of the float would affect all the pumps, perhaps—if the float happened to stick in its raised position—turning them all on to run all night. With the control system described this cannot happen, because even if one relay should fail, the others will operate.

THE DAILY LOG

Aurora, Illinois

By Walter A. Sperry, *Superintendent*

January 12—Freezing of the supernatant line from two digesters caused a day's cold wet work today. The line was frozen solid with a heavy, greasy sludge that was discharged into it from the grease skimming tank. Rodding was impossible. A local electric welder's outfit (D.C. generator) was requisitioned. The results were only partially successful due to the size of the pipe and not enough amperage. A stream of water from a hose, in combination with much back-breaking rodding, finally broke the plug loose.

January 15—A quarter of a square mile of new territory was added to the Sanitary District in four parcels during 1953. This brings the total area of the District up to an even 14 sq. mi. Accordingly, today the office map, our attorney's map, and that of the Township Assessor and the Chamber of Commerce were all brought up-to-date as of December 31, 1953.

January 19—The first gas-fueled engine used at Aurora was an 11-hp. engine used to power a 4-in. pump, to dewater clarifiers and fill the digesters. The arrangement was one of the most useful about the plant, but was used only infrequently. Due to long periods of standing the engine got so temperamental that we often had to fight it for several hours before we could get it to run. The Chief Operator got tired of this repeated performance and came in with the suggestion that we transfer a 10-hp. electric motor from a nearby

blower that is seldom used, if the engine base could be modified to receive it. It was to be transferred back when needed on the blower. The starting switch on the blower would serve for both. The change was made and it worked, except that the motor ran too fast. The idea was so appealing, however, that soon a reconditioned motor of the proper speed was found for $150. Now everyone is happy. The old engine was stripped and junked.

January 22—About a year ago two gas meters were changed from the warm furnace room to the digester house. We thereby improved the piping arrangement, but during the winter, due to the cold room, the meters acted as moisture condensers and gave constant trouble from water collecting between the diaphragms. Periodically the meters had to be disconnected and the water removed, an annoying and time consuming job. An experiment with two ½-gal. milk bottles filled with marbles and placed in series collected water in the first bottle but not in the second. We thought the problem, then, could be solved by filling an oil drum with small rounded stone and connecting it in the line. It did not work. As a second try, we built a Celotex housing around the two meters, placed a bank of lamps inside, and arranged it for easy dial reading and the removal of meters. In addition, the piping from the digesters to the meter housing was insulated with wool felt. This maintained a temperature around the meters at near 60° F. and there has been no condensation trouble since.

January 25—Operating days are made interesting by the surprises. A highway engineer from the County office came in this afternoon with three large rubber bladders to be blown up with plant gas, on his theory that it would make them buoyant. These were for a transit shot a mile or so away for road survey work. We objected that it would not work, as plant (digester) gas had a specific gravity of about 0.88. Why not use hydrogen? No hydrogen was available. We blew up one of the bladders with plant gas from our pressure storage tank to satisfy him. Finally, to be a good neighbor, we rigged up a Gooch filter flask with a rubber stopper and short tube, wrapped a towel around the flask, attached the balloon to the tube of a second Gooch flask to act as a trap, added some zinc and hydrochloric acid, and held our finger on the tube to develop pressure. We blew the balloons up to some 18 in. in diameter. The improvised stunt worked and both of us were happy.

January 28—A class of eight from the nurses training school of St. Charles Hospital spent 2 hr. today in discussion and a plant visit. The public health aspects of water supply, sewage treatment, garbage disposal, milk, rats, flies, etc., were talked over. This is their one opportunity to get some idea of Public Health Engineering.

February 3—Billed the Public Service Company for $348.00, with an explanatory letter, to compensate for delay and trouble in cleaning an 8-in. sewer in River Street, after wasting 2½ days time. We finally found out that the electric utility had set a pole exactly over the sewer, which was in the parkway, and then proceeded to drive a ⅝-in. ground rod, some 12 ft. long, exactly through the center of the sewer. Fortunately, the tile only had two round holes, no breaks. When the next pole was set there they demanded that a Sanitary District man stand by some 5 hr. as an inspector.

We have always felt that too many routine records are not always enough. They, in time, serve useful purposes. Take the wind direction record, for instance. Ever since our odor suit we have kept an all-day, 2-hr., wind direction record, recorded at sampling time from a wind direction indicator placed in the laboratory. One day last fall the Park Board asked us if we

could tell the wind direction at noon some 10 days previously. We obliged, and asked what that was all about. On that day the Park Board was arsenic spraying a bridle path, with orders to cut off the sprays at noon. This they failed to do. As a result, a $2,200 cow was killed and another fine cow and calf were seriously injured, much to everyone's embarrassment. The wind direction given fitted the story given to their insurance company and they collected in full.

February 10—Today the District President and the Superintendent were appointed by the Mayor as members of a City Planning Commission. We were also assigned to the Executive Committee, as were members from all other taxing bodies. This may well be a a two-year job demanding much time and adding responsibilities.

February 15—Our highway "Welcome" sign has lasted for many years. It was made from white pine plank—it is doubtful if we could buy as good today. The letters were cut from stainless steel, black enamel baked and mounted on under-letters cut from Masonite. It looked a bit frowsy and today we brought it in for a face lifting. It was generally in excellent condition, but the tops of the supporting posts showed some failure. We added the protection of two pyramid-shaped caps of stainless steel. It will still serve for many years.

February 23—Addressed the local Exchange Club on the subject of "Adam's Ale—Water." Most folks think water is just something to drink and keep clean with. Actually, it is the most remarkable, unusual, and necessary fluid that exists. It is difficult to crowd into a half hour a bare outline of water's role in all that affects man.

February 26—The type of traction clarifier used at this plant has a grease skimming arm some 40 ft. long that is operated by a heavy weight and chain. This morning and after some 20 years, we found this chain broken—fortunately it did not catch in the plow system to do more damage. This necessitated dewatering the tank to make repairs. It was a good thing, for we found our flow directing baffles in bad shape and these were overhauled. Later, fluorescein dye tests were made on all three clarifiers. The tests checked the average suspended solids removal of 57.9 per cent for the months of January and February. Before these baffles were installed the three clarifiers were only removing some 30 to 35 per cent of the suspended solids, due to short circuiting.

March 2—For those who operate gas-fueled engines this note may contain a useful germ of instruction. Also, it is a lucky Superintendent who has nearby a well-informed salesman. Aurora's two pump engines have an automobile starting system with batteries and starting motor. These batteries operate at 12 v. and have 81 plates; they cost some $80 apiece. For some time we have felt that the 12 to 15 months service they gave was not enough. Then one day a salesman offering 10- to 20-year life nickel-cadmium batteries gave us the idea of investigating the possibility of battery elimination by the use of a selenium rectifier. This called for a battery test for demand output. Much to our surprise we got readings of 800 amperes. From this we found that the rectifier would cost $850 for a 500-amp. continuous output instrument and that any higher amperage output would cost considerably more. Therefore, this idea was ruled out. Then we called in an excellent battery man. He made a thorough instrument check and came up with the statement that those batteries should give 2 to 3 years of service. He pointed out that we had two troubles—top leakage across the terminals and burning out of the batteries by over-charging. His remedy for the

former is to keep the battery tops cleaner; for the latter, a small rheostat placed on the engine generator to cut its output to the batteries so as to equal more nearly the drain on the battery by the engine ignition and controls.

March 15—Any sewer, interceptor or local, added to existing sewers in Illinois towns must have a state permit, which specifies that they may not receive roof water, ground water, or storm water. On this fact hangs the following troublesome tale.

A local housing development laid all its sewers under District supervision and the District gave them outlets to its system in Pleasant Place and Montgomery Road. All roof water was excluded. Subsequently, a house on Pleasant Place at the junction with the housing project connection severely flooded after every heavy rain. Later, other basements in nearby houses were flooded, and finally one on Gates Street, a block away. This flooding had occurred periodically over a period of 4 to 6 years, causing protest to the District. Meantime the housing development was also subjected to severe storm-water flooding from water on higher ground nearby. Throughout this period field surveys failed to uncover the source of what it was confidently believed was storm water. Sealing of manhole covers did not help.

Then one Sunday at 4 PM there was a 2.3-in. rain that fell in 57 min. according to our plant recording rain gage. Even our President's basement was flooded, as well as others all over town. All h—l broke loose on Pleasant Place and Gates Street. A stormy meeting with the Board threatened damage suits. This resulted in a more drastic survey. The tank truck of the nearby village fire department was requisitioned and a crew of men systematically tested every catch basin in the whole area with fluorescein dye.

The result was to discover at least four cleverly concealed outlets from the backs of catch basin traps that led directly to the street sewer—all despite the several years of denial of such connections and what seemed to be cooperation to help locate the trouble. The connections were all dug up, and the tile broken and sealed with concrete. No rains of sufficient volume or intensity have occurred since to test the thoroughness of the work. At least one more such connection is suspicioned.

PORTABLE POSTS PROTECT PLANT LAWN

By R. Grinnell

Superintendent, Sewage Treatment Plant, Birmingham, Mich.

The driveway from the main road into the Birmingham, Mich., sewage treatment plant looks as if it might be a through road. Of course there is a sign at the entrance of the driveway that says "DEAD END—THIS IS NOT A THROUGH ROAD," but no one pays any attention to signs.

People who mistake the driveway for a through road drive in, only to be brought up sharp at the plant garage door. That exasperates them. Their first impulse is to get out of there as fast as possible and back out on the road. And the easiest way to do that, of course, is to take off right across the lawn.

Now we don't like that. We are proud of our lawn and like to keep it in first-class shape. And these exasperated people have made the plant crew a lot of work.

How to stop them? A fence, and then a hedge, was considered, but neither was liked. Finally it was decided to use a row of fence posts set in the ground just close enough together to keep a car from going through.

But that idea had its disadvantages. In the damp soil fence posts rot off right at the ground and the part below ground has to be grubbed out to prevent it being a hazard to the lawn mower. Besides, a row of posts along the driveway would increase considerably the time spent hand trimming with the grass shears. There is too much of that now. It takes about 6 hr. of steady plugging with a power mower to cut the lawn. After that it takes almost as long to trim around the buildings, trees, etc., with the hand shears. The help seem to enjoy running the power mower, but they have to be driven to do the trimming.

There is still another disadvantage to the posts: they are pretty solid. One could inadvertently back a car into one and do considerable damage to a bumper or a fender.

FIGURE 1.—Solid appearing guard posts protect lawn from damage by cars turning around in dead-end plant driveway.

FIGURE 2.—Posts actually are dummies held in position by ⅝-in. reinforcing rod jabbed in ground. They are removable for mowing lawn with power mower, eliminating hand trimming.

The problem was how to have all the advantages of a row of posts and none of the disadvantages. Figures 1 and 2 show how it was worked out. Figure 1 shows posts all in a row, solid as all get out. But Figure 2 reveals that they are pretty much a fraud.

It is easy to see (Figure 2) how the "stage prop" lawn guards were made. A standard fence post was cut into three or four sections, then a ⅝-in. hole was drilled about 12 in. into the bottom and a piece of ⅝-in. reinforcing rod was driven into the hole. The rod should be about 30 in. long.

It is also easy to see how the disadvantages of a row of solid posts were overcome. The rotting out at the ground is not now a problem. And when the lawn needs mowing the posts are lifted out and set aside until the mower is past—and no hand trimming is required. And lastly, if someone should inadvertently back into one, he would just tip it over; but the exasperated people, of course, don't know that.

INTERESTING EXTRACTS FROM OPERATION REPORTS

Attention operators! It will be appreciated if copies of all annual reports of both large and small plants are sent to the Federation office for abstracting in this section of the Journal. Carbon copies of typewritten reports will be promptly returned on request. Please direct annual reports to: Federation of Sewage and Industrial Wastes Associations, Room 325, Illinois Bldg., Champaign, Ill.

20th Annual Report of the Minneapolis-St. Paul (Minn.) Sanitary District for the Year 1952 *

By Kerwin L. Mick

Chief Engineer and Superintendent

General

The average flow for 1952 was 135.2 m.g.d., establishing a new record for the second successive year, and represents an increase of 3.3 m.g.d. from the 1951 flow of 131.9 m.g.d., with the maximum daily flow through the plant of 187.5 m.g. being received on June 27.

From an estimated tributary population of 907,000 in 1952, the following per capita values obtained:

1. Sewage flow, 149 g.p.c.d.
2. Suspended solids, raw sewage, 0.32 lb. per cap. per day.
3. B.O.D., raw sewage, 0.21 lb. per cap. per day.

Assuming 0.17 lb. of 5-day B.O.D. per capita per day for domestic sewage only, the population equivalent of the sewage and wastes received at the plant during 1952 was 1,140,000, or 26 per cent greater than the estimated population of 907,000. Industrial wastes account for the major part of this difference, and according to these figures would amount to 20 per cent of the pollution load on the plant.

In regard to the raw sewage strength as compared with 1951, the solids content increased with the total solids averaging 765 p.p.m., and the suspended solids 256 p.p.m., compared to 750 p.p.m. and 251 p.p.m., respectively, in 1951. The B.O.D. decreased to 172 p.p.m. in 1952 compared with 184 p.p.m. in 1951. This may have been in part due to dilution of the sewage from the extreme thaw and wet weather conditions experienced in the early spring and summer.

The extreme ranges in raw sewage strength during the year are also of interest, in contrast with the average values. The B.O.D. was at a minimum of 53 p.p.m. on Sunday, March 30, due to the dilution of the normally weak Sunday sewage by heavy thaw flows and runoffs into the sanitary system. The maximum B.O.D. of 330 p.p.m. occurred on Wednesday, October 8. In terms of suspended solids the raw sewage strength was at a minimum of 96 p.p.m. on Sunday, August 31, and a maximum of 840 p.p.m. on June 13, when the sewage contained unusual quantities of solids flushed through the interceptor sewer by an extremely heavy rain during most of the day.

Sludge Conditioning and Filtration

In 1952 the chemical dosages required to condition the sludge for fil-

* For last previous extract see This Journal, **24**, 3, 331 (Mar., 1952).

tration show a marked increase, especially during July, August, and September, as compared with 1951. Even if chemical prices had remained the same in both years, the chemical cost per ton of sludge solids filtered was up 18.7 per cent in 1952 over 1951. Increased difficulty was experienced with blinding on the filter cloths, necessitating more frequent washing and acid baths. This is believed to be principally the result of an increasing content of oils, fats, and greases (and perhaps detergents) in the sludge and is tied in with the increasing difficulty being experienced in moving the sludge through the pipe lines. This first became noticeable about four years ago when deposits began to build up on the walls of the pipe lines. Since that time, it has been necessary to scrape out these deposits at intervals ranging from five months down to six weeks.

At first this periodic cleaning of the pipe lines was necessary only in the two 8-in. lines between the raw sludge pumps and the concentration tanks, a distance of about 320 ft. Later the two 6-in. lines from the concentration tanks to the bucket elevators, a distance of 150 ft., had to be cleaned two to three times a year, whereas formerly they were cleaned once a year or less. Late in 1952 these two 6-in. lines were replaced with 8-in. pipe.

The deposits on the walls of the pipe lines occur only on the discharge side of the raw sludge pumps, no deposits having occurred in the suction lines to the pumps. Perhaps the churning action in these piston pumps, under pressure, together with the increasing grease content of the sludge, has resulted in a separation of greasy material, which then adheres to the walls of the pipe.

An average of 318 tons of filter cake was produced daily, containing 102 tons of dry solids. The total quantity of wet filter cake produced during 1952 was 105,098 tons. The quantity of sludge produced was considerably higher than antipicated at the time of design, when it was expected that an average of 76 tons of dry sewage solids would be removed daily. The increased quantity is due to higher sewage strength and greater removals by the plant than originally anticipated.

Maintenance and Equipment Changes

New steel wire screens were installed on filters No. 1, 2, 4, 6, 7, and 8, and new wood division and drainage strips on filters No. 1, 2, 4, and 6. The average life of the screens is approximately 18 months due to loss of metal during acid baths.

The agitator top rollers and bearings were replaced on filters No. 1 to 6, inclusive. It was necessary to replace or sleeve some of the agitator arms when corrosion had weakened or made holes in them. A new wash-water trough was installed on filter No. 2.

The bearings and gears were replaced in the gear reducer of bucket elevator No. 1.

The north collector belt was replaced this year after more than seven years of service and after several patches and splices had started giving way. A new gear motor was installed in the south sludge cake leveler.

A new air and vacuum impulsed diaphragm pump was installed to pump ferric chloride from the outside storage tank to the two 1,000-gal. storage tanks on the feeder floor.

The collector chain, drive chain, and two flights were replaced in the west sludge concentration tank. The 8-in. sludge inlet pipe in the east concentration tank was revised for easier cleaning. The collector chain in the east concentration tank was turned over, attachment links replaced, and seven new flights installed.

The maintenance work on the four incinerators was minor except for the button bearing at the bottom of the

central shaft on No. 3 incinerator. To replace this, it was necessary to jack up the entire central shaft and rabble arms, then dismantle the cooling air housing. Two 20-ton jacks and a special beam section were used in the raising of the central shaft. Two rabble arms were replaced with old rebuilt arms and two rabble teeth were replaced with two used teeth.

The inner lining of the chimney was repaired by a contractor this year. The top 8 ft. of acid-resistant brick were replaced.

The exterior brick and stone of all the buildings was pointed up this year.

The 16-year-old underground oil tank serving the Administration Building sprang leaks. A new, smaller tank with float control was installed in the tunnel area near the boiler room.

Several pumps of all types were completely overhauled. The planned preventive maintenance of equipment, especially motors, motor controls, and relays, has resulted in few emergency break-downs. There are more than 325 motors, ranging to 75 h.p.; 400 or more breakers; and many relays and automatic equipment in the plant.

Table I is a summary of the plant operating data for 1952.

TABLE I.—Summary of Operating Data for 1952 at Minneapolis-St. Paul, Minn.

Item	Average
Rainfall (in.)	23.66
Est. tributary population	907,000
Equiv. pop.	1,140,000
Sewage flow (m.g.d.)	135.2
Screenings (cu. ft./m.g.)	0.7
Grit removal:	
Amount (cu. ft./m.g.)	4.6
Volatile solids (%)	8.1
Dissolved oxygen (p.p.m.):	
Raw sewage	1.25
Settled effluent	4.65
Settling tank detention (hr.)	1.4
B.O.D., 5-day:	
Raw sewage (p.p.m.)	172
Settled effluent (p.p.m.)	103
Removal (%)	40.1
Suspended solids:	
Raw sewage (p.p.m.)	300
Settled effluent (p.p.m.)	77
Removal (%)	74.0
Settleable solids:	
Raw sewage (ml./l.)	5.9
Settled effluent (ml./l.)	0.24
Removal (%)	95.3
Volatile solids (%):	
Suspended, raw sewage	71.1
Susp., settled effl.	73.4
Total, raw sewage	46.2
Total, settled effl.	38.2
Raw sludge:	
pH	6.0
Total solids (%)	7.8
Volatile solids (%)	68.3
Thickened sludge:	
pH	5.8
Total alkalinity (p.p.m.)	1,000
Total solids (%)	8.7
Volatile solids (%)	68.5
Filter cake:	
Total solids (%)	32.0
Volatile solids (%)	65.3
Produced (wet tons/day)	317.5
Produced (dry tons/day)	101.6
Conditioning chemicals:	
CaO (lb./100 lb. dry sol.)	3.02
$FeCl_3$* (lb./100 lb. dry sol.)	1.22
Sludge filter rate:	
Wet cake (lb./sq. ft./hr.)	9.4
Wet cake (lb./sq. ft. filter area used)	0.92
Incineration:	
Combustibles (tons/day)	65.0
Moisture evap. per ton of combustibles (tons)	3.4
Ash produced (dry tons/day)	35.7
Power (kw.-hr./ton dry sol.)	9.3
Fuel oil (gal./ton dry sol.)	0.57
Filter cake disposal:	
For fertilizer, total (dry tons)	683.5
Incinerated (dry tons/day)	99.5

* Ferric sulfate used, but calculated to equivalent $FeCl_3$.

Annual Report of the Bureau of Sanitation, Los Angeles, Calif., for the Fiscal Year 1951–2

By Warren A. Schneider

Waste Disposal Engineer

General

The Los Angeles Bureau of Sanitation consists of an Administration Division, a Refuse Collection Division, a Sewer Maintenance Division, and an Incineration Division. In addition, the operation of the Hyperion sewage treatment plant has, since May 1, 1952, been a function of this Bureau, with the new Sewage Treatment Division responsible for such operation. The Sewer Maintenance Division is supervised by Alvin A. Appel, Sewer Maintenance Superintendent; the Sewage Treatment Division, by Geoffrey A. Parkes, Engineer Superintendent.

Terminal Island Plant

For the disposal of sewage from the Harbor area, a treatment plant is operated at Terminal Island by the Sewer Maintenance Division. After primary treatment and separate sludge digestion, the effluent is disposed of into the ocean through a 30-in. cast-iron pipe outfall 1,000 ft. long. The design capacity of this plant is 7 m.g.d. During 1951–52 the average flow was 5.8 m.g.d., which is 83 per cent of design capacity. After digestion, the sludge is dried on sand beds and sold for low-grade fertilizer.

The gas produced from the digestion of the sludge is stored and used to heat the digesters and for incineration of bar screenings.

In May 1952, the sludge collector equipment in the clarifier was replaced at a cost of $18,000, after 16 years of continuous operation. In conjunction with the replacement of the old equipment, a cathodic protection system was installed to protect the new equipment from corrosion and electrolytic action.

Operating data for 1951–2 are summarized in Table II.

Hyperion Plant

The Hyperion sewage treatment plant, situated on the shore of Santa Monica Bay near El Segundo, serves an estimated population of 2,350,000 residents of Los Angeles and certain adjacent cities. The sewage flow to the plant during the year averaged 219 m.g.d. With the normal growth in population and continued extension of sewers into currently unsewered dis-

TABLE II.—Summary of Operation Data, Los Angeles Terminal Island Sewage Treatment Plant for the Fiscal Year 1951–2

Item	Average	Item	Average
Sewage flow (m.g.d.)	5.66	Gas produced (cu. ft./day)	81,138*
Suspended solids (p.p.m.):		Gas used for heat (cu. ft./day)	18,000
Raw sewage	392	Volatile solids (%):	
Settled	190	Raw sludge	71.3
Removal (%)	51.6	Digested sludge	51.9
Settleable solids (ml./l.):		Operating costs ($):	
Raw sewage	11.1	Labor	40,378
Settled	2.4	Power	845
Removal (%)	78.4	Light	513
Sludge (g.p.d.)	19,069	Water	670
Solids (%)	5.9	Miscellaneous	3,468
Digester temp. (°F.)	92.5	Total	46,074
Dig. loading (lb. dry sol./day)	9,457	Per m.g.	23.25

* Maximum day, 177,600 cu. ft.

tricts, both of these figures are on the increase. In this connection, it is estimated that by 1954 the flow of sewage will have reached the present design capacity of the plant at 245 m.g.d. It should be noted that when the nominal designed capacity of the plant has been reached, the plant can continue to treat sewage at a considerably increased rate without serious impairment of the efficiency. In fact, operating experience has proven that most of the units of the plant can treat sewage and sludge in considerably greater quantities than was anticipated at the time of design. Only the secondary treatment sections of the plant will require expansion in the immediate future.

The Hyperion plant represents a total capital outlay of approximately $43,000,000, and for the fiscal year 1951–52 required an operating budget of $1,645,756. The number of employees varied through the year, but averaged 286 in all classes.

Detailed descriptions of the design and construction of the plant have been published elsewhere, but for purposes of reference may be described herein as comprising the following: bar screens, detritors, pre-aeration, primary settling, secondary treatment consisting of aeration, final settling, chlorination, and disposal at sea through a submarine outfall 1 mi. long. Sludge handling facilities consist of: digestion, gas collection, elutriation, vacuum filtration, heat drying, and sacking of fertilizer for sale. All plant power and aeration air is produced in the power plant, where digester gas is the principal source of fuel in gas diesel engines.

Although the plant was operating on a plain aeration basis for most of the year, the over-all removals of suspended solids and 5-day B.O.D. were surprisingly good, being nearly 70 per cent in both cases. Chlorination was practiced only during the summer bathing season and was discontinued during the winter months.

The over-all reduction of volatile matter accomplished by digestion is shown to be 55.2 per cent, while gas production averaged 18.2 cu. ft. of gas per pound of volatile solids reduced. The plant is entirely self-sustaining in terms of power source, approximately 94 per cent of the total fuel used being digester gas. Waste heat from the engines and exhausts is recovered in the form of steam, which is used to heat the digestion tanks by direct injection.

When the secondary treatment processes were first placed in service in May 1951, large masses of froth were formed when the air was applied at the rate required for treatment. This unexpected difficulty, which has since been reported at many other sewage treatment plants, is believed to have been caused by the extensive use of synthetic detergents in homes and industry. Hand hosing of the foam proved ineffectual and masses of foam were carried by the sea breeze into adjacent communities with resulting complaints. The immediate solution was to reduce the air supply to the aeration tanks and place the secondary treatment on a plain aeration basis. Construction of an extensive system of water sprays and the intermittent use of anti-foam chemicals has brought this vexatious condition under control, and by May 1952 permitted the high-rate activated sludge process to be put into operation.

An unexpectedly high air demand has been experienced at this plant, being in the order of 0.75 cu. ft. of air per gallon of sewage, as compared with the 0.53 cu. ft. used in design. This is probably due not only to the fact that the sewage received at the plant is relatively strong, but also to the fact that the time of flow in the very lengthy sewer system of Los Angeles results in the sewage arriving at the plant in a stale condition, devoid of dissolved oxygen and bordering on septicity.

Sludge Filtration Experiments

Although by ordinary criteria sludge digestion has been satisfactory, digested elutriated sludge has produced very low yields with high coagulant demands in the mechanical dewatering operation of the vacuum filters. This difficulty was first believed to be caused by unskillful operation of the filters themselves or by incorrect selection of filter blanket materials. Extensive experimentation both in the plant and the laboratory, however, proved that long-nap woolen blankets are the best suited for this purpose. In an endeavor to determine whether the problem was basically one of digestion, variations in the digestion processes were tried throughout the year in selected tank groups. These variations included ranges in detention time between 20 and 70 days, tank temperatures at 85°, 95°, and 120° F., single-stage, two-stage, and three-stage digestion, and concentrations of elutriated sludge. The effects of these process variations on vacuum filtering rates were inconclusive. However, one outstanding conclusion was derived from these experimental operations in that digester loading could be increased far beyond the design rates without detrimental effect upon digester operation. In fact, it was discovered that troublesome scum formations were eliminated by high digester loading rates.

In January, the use of hydrated lime in addition to ferric chloride was begun in an effort to improve filter operation. The cost of the lime was offset by the reduced use of ferric chloride, and increased filter yields indicated promising results. However, rapid clogging of filter cloths and the reduced nitrogen content of the finished fertilizer product caused abandonment of this process at the end of March.

The final fertilizer product produced by the flash drying system has proven to be extremely fine and dusty, and designs have been underway for the installation of equipment to pelletize and granulate this material, in which form it is believed that it will be more acceptable to the ultimate consumer. Pending the installation of this equipment, the entire output of non-pelleted fertilizer has been sacked and sold under an interim contract to a fertilizer dealer.

A large number of different types of filter cloths have been tested. These include most of the new synthetic fibers, both spun and extruded, glass, and many types of weaves in synthetics, cotton, and wool. However, the presently used wool blankets seem to be indicated as best at this plant if the present price levels continue and if other fabrics are available only in sewn cloths. A great deal of information of substitute cloths is available if the wool blankets cannot be obtained.

As part of the filter cloth investigation, methods of cloth cleaning were tested and developed. At present, the under filter drums are filled with inhibited 10 per cent hydrochloric acid and the drums are revolved in the acid for about 3 to 4 hr. During this period the blow portion of the cycle is in operation so that back-washing is accomplished. The cloths are restored to about 80 or 90 per cent of their original condition. No cheaper or better method has been developed, although experiments with detergent materials in the laboratory indicate that methods using detergents and acid may be desirable. Experiments concerning this are being conducted.

Various types of precoating materials were tested to see if precoat filters would be of value at this plant. It was found that diatomaceous earth precoats were effective and could compete with cloths in cost and production if the filters were equipped for such operation. Since considerable costs would be involved in filter conversions and since no substantial increase in rate was found, precoats are not indicated for this plant. The advantage

of the precoat filter is the ease of placing the filter media and the fact that a constantly fresh filter surface is available.

Tests showing the effect of elutriated sludge concentration on filtration were made in the laboratory and on a pilot-plant scale. These indicated that substantial increases in filter rate would occur. When tried on a plant scale, it was found that concentration in large tanks took so long that substantial amounts of alkalinity developed, with a consequent increase in coagulant demand and decrease in filterability.

The effect of high temperature (120° F.) sludge digestion on sludge filterability and coagulant demand was thoroughly tested on a laboratory scale. This showed that a very different group of organisms developed at the high temperatures and that the resulting sludge had fewer fine solids and less organic nitrogen, but filtered well.

TABLE III.—Summary of Operation Data, Los Angeles Hyperion Sewage Treatment Plant for the Fiscal Year 1951–2

Item	Average
Est. trib. population	2,350,000
Sewage flow (m.g.d.)	218.67
Gal./cap./day	93
Grit removed (cu. ft./m.g.)	263
Pre-aeration time (min.)	33
Air supply (cu. ft./gal.)	0.08
Sed. tanks, det. period (hr.)	1.24
Flow (g.p.d./sq. ft.)	2,193
Skimmings (cu. ft./m.g.)	22.8
Aeration tanks, det. period (hr.)	3.24
Air supply (cu. ft./gal.)	0.53
Diss. oxygen, effl. (p.p.m.)	2.4
Final tanks, det. period (hr.)	1.95
Flow (g.p.d./sq. ft.)	1,400
Settleable solids:	
Raw sewage (ml./l.)	1.38
Settled (ml./l.)	0.17
Removal (%)	87.7
Susp. solids:	
Raw sewage (p.p.m.)	345
Volatile (%)	81.2
Settled (p.p.m.)	180
Mixed liquor (p.p.m.)	215
Ret. sludge (p.p.pm.)	2,106
Final effl. (p.p.m.)	104
Removal	69.9
B.O.D., 5-day:	
Raw sewage (p.p.m.)	215
Settled (p.p.m.)	120
Final effl. (p.p.m.)	66
Removal (%)	69.3
Grease:	
Raw sewage (p.p.m.)	134
Settled (p.p.m.)	71
Chlorine demand:	
Raw sewage (p.p.m.)	19.1
Final effl. (p.p.m.)	9.7
Removal (%)	49.2
Chlorine used, total (tons)	1,704.8
Raw sludge:	
To digester (m.g.d.)	1.15
Solids (%)	6.41
Vol. solids (%)	74.5
Solids, dry (lb./day)	596,200
Solids, vol. (lb./day)	442,700
Digested sludge:	
Withdrawn (m.g.d.)	0.59
Solids (%)	3.70
Solids, dry (lb./day)	185,300
Supernatant:	
Withdrawn (m.g.d.)	0.53[1]
Solids (%)	2.59[1]
Solids, dry (lb./day)	117,600[1]
Gas prod. (1,000 cu. ft./day)	4,395
Cu. ft./lb. vol. sol. red.	18.2
Elutriated sludge:	
Withdrawn (m.g.d.)	374[2]
Solids	4.30
Solids, dry (lb./day)	132,500
Vacuum filtration:	
Filter operation (hr./mo.)	4,870
Cake, wet (tons/day)	270.69
Solids, dry (%)	27.3
Solids, dry (tons/day)	74.15
Yield (lb./sq. ft./hr.)	1.59
$FeCl_3$ (%)	5.54[3]
Sludge drying and incin.:	
Operation time (hr./mo.)	673
Moist. evap. (tons/day)	209.41[4]
Sludge dried (tons/mo.)	1,833
Sludge incin., total (tons)	54.2
Operating costs ($):	
Salaries	1,052,559
Materials and supplies	572,784
Total, gross	1,625,343
Revenue, fert. sales	114,051
Total, net	1,511,292
Net per m.g. treated	18.90
Net per capita per yr.	0.64

[1] Average of 11 months.
[2] Average of 10 months.
[3] Lime also used during Jan., Feb., and Mar. 1952.
[4] Based on operating days only.

Plant-scale tests confirmed the laboratory work. Tests were then made with mixtures of 120° F. and 85° F. digested sludge and it was determined that it was possible to obtain mixtures which gave improved filterability and low coagulant demand with adequate organic nitrogen content. Experiments were made filtering mixtures of return activated sludge and 120° F. digested sludge. This was shown to be feasible on a plant-scale test.

A number of new coagulating agents were tried. These included the acrylic polymers like Monsanto Chemical Company's "Krillium," American Polymer Company's "Agrilon N," and similar material from American Cyanamid Company, and Carbide and Carbon Chemicals. It was found that the Monsanto and American Polymer materials were promising and should be considered for plant use if price levels dropped. Adding these polymers followed by ferric chloride produced yields as high as 15 lb. per square foot per hour. If the present $1.00 per pound price drops, these materials should become of great interest. Other coagulants tried included:

1. Ammonium lignin sulfonate.
2. Waste sulfite and sulfate liquor by-products:
   (a) Orzan SL–45 (Crown Zellerbach).
   (b) Orzan L–50 (Crown Zellerbach).
   (c) By-Lig (Monsanto).
   (d) Indulin C.
3. Activated carbon.
4. A large number of other proprietary chemicals.

A total of 1,000 different filtration tests were made during the year. These have opened avenues of further investigation which will have to be pursued in the coming years. However, a much better understanding has developed of the problems to be overcome, and methods of approach to these problems which give much hope of their solution have become apparent. Much basic research must still be accomplished, but the problem does not look as formidable as it did at the beginning of the year.

In general, the operating results of the plant have been highly satisfactory. The standards set by the California State Department of Public Health with respect to beach pollution have been fully maintained and operations conducted in such a manner that basic plant objectives have been reached. Operating data are summarized in Table III.

1st and 2nd Annual Reports of the Fond du Lac, Wis., Sewage Treatment Plant for the Years 1952 and 1953

By C. W. Bogenhagen

Superintendent

1952

The year 1952 was more or less the guidepost for operating cost at the sewage treatment plant. Pumping and treatment remained about the same, with cost for sludge treatment going up. Sludge drying equipment started with a drying schedule of 8 hr. per day in January, increasing to 20 hr. per day in November and December. This required two extra men for the department. Another man also was added part time to the incinerator staff to take care of the 45-hr. week that went into effect in November.

A full year of weather data was kept showing a total precipitation of 28.59 in. A temperature of − 18° F. was the coldest on record. The warmest day was July 12, when a high of 94° was

recorded. There were five days of below zero temperatures and seven days of 90° or above. A total of 43.03 in. of snow fell during the year.

Average flow at the plant was 3.64 m.g.d. on domestic; 0.55 m.g.d. for the tannery; for a total average of 4.19 m.g.d. Total storm water by-passed at the old pumping station amounted to 67.20 m.g. From the total pumpage of 1,593.02 m.g., 1,690 tons of dry sewage sludge were produced.

Gas production averaged about 1.52 cu. ft. per person per day for the city of Fond du Lac, against a national average of 0.75 cu. ft. per person per day. This increase is due to solids from the tannery and also additional garbage

TABLE IV.—Summary of 1952 and 1953 Operating Data for the Fond du Lac, Wis., Sewage Treatment Plant

Item	Average 1952	1953
Population served	29,918	29,936
Rainfall (in.)	28.59	22.06
Sewage flow treated:		
Total (m.g.d.)	4.19	4.04
Domestic (m.g.d.)	3.64	3.47
Tannery (m.g.d.)	0.55	0.60[1]
Per capita (g.p.d.)	122	135
Screenings, tannery:		
Total (cu. yd.)	433	209
Per m.g. (cu. yd.)	790	1
Grit, total (cu. yd.)	261	372
Per m.g. (cu. yd.)	1.74	0.25
Solids (%)	59	58
Volatile (%)	45	42
Settleable solids (p.p.m.):		
Domestic	20.5	17
Tannery	29.4	26
Combined	30.0	22
Effluent	0.38	0.59
Reduction (%)	98	97
Suspended solids (p.p.m.):		
Domestic	995	1,040
Tannery	890	1,630
Combined	832	1,090
Effluent	134	47
Reduction (%)	84	96
B.O.D., 5-day (p.p.m.):		
Domestic	228	209
Tannery	472	487
Combined	472	259
Effluent	41	43
Reduction (%)	91	83
pH:		
Domestic	7.4	7.2
Tannery	9.9	9.5
Combined	8.7	8.1
Effluent	8.2	7.9
Raw sludge	7.2	7.1
Gas prod., total (mil. cu. ft.)	16.49	16.25
Per capita (cu. ft./day)	1.52	1.49
Per m.g. sewage (cu. ft.)	10,800	11,100

[1] Based on 346 days.

TABLE IV.—(*Continued*)

Item	1952 Average	1953
Vacuum filters:		
Run monthly (hr.)	310	715[2]
Run per work day (hr.)	13	15
Rate (lb./hr.)	935	1,160
Sludge filtered, total (m.g.)	3.88	52.77
Solids (%)	—	9
Cake moisture (%)	—	64
Dry solids (tons)	—	2,093.4
Dry solids (%)	—	84
CaO, total (tons)	232	318
$FeCl_3$, total (tons)	38.75	54.25
Fuel oil used, total (gal.)	28,353	52,771
Operating costs ($):		
Salaries	56,038.41	63,532.57
Light and power	13,959.34	15,450.51
Water	1,032.73	753.95
Fuel	1,095.54	1,293.91
Equip. maint. and repairs	25,762.91	37,736.69
Build. and grounds maint.	2,151.46	346.35
Miscellaneous	1,583.30	1,694.28
Total	101,633.69	120,808.26

[2] Total for two filters 6 ft. by 8 ft.

grinders being installed in the city. A total of 16,488,687 cu. ft. of sludge gas was produced during the year.

1953

In 1953 the cost of sewage treatment plant operation increased due to wage increases, repairs, and a full year of sludge filtering and drying, with operation costs for the pump stations and the incinerator staying about the same.

Low precipitation was reflected in a reduction in peak and average flows. As a result, only 48.87 m.g. of storm water were by-passed at the old pumping station. Also, with additional drying hours, 2,093 tons of dry sludge were produced from the 1,474.54 m.g. treated.

Gas production averaged about the same as for the previous year at 1.5 cu. ft. per person per day, or 11,100 cu. ft. per m.g. of sewage treated.

Operation data for 1952 and 1953 are summarized in Table IV.

WRENS ENLISTED IN FIGHT ON FILTER FLIES

By Roy Binder

Superintendent, Sewage Treatment Plant, Hays, Kans.

If an experiment now being carried out at the Hays, Kans., sewage treatment plant is successful, gourds grown on the plant grounds may indirectly prove to be the answer to the plant's filter fly nuisance problem. D.D.T. has been used at the plant with success in the past to control the *Psychoda*, but seems to be becoming less effective.

The whole scheme was conceived when it was noticed that the wrens visiting the plant from nearby Big Creek feed on the adult *Psychoda* flies, and that they might even eat the larvae if not frightened off the filter media by the rotary distributor arms. Casual research revealed that insects comprise 90 per cent of a wren's diet, whereas

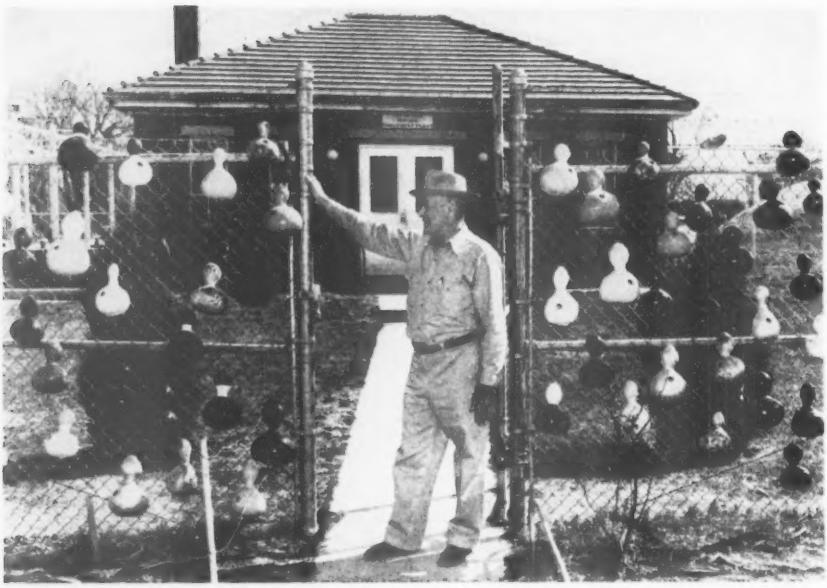


FIGURE 1.—Inexpensive wren houses made from gourds will be hung about grounds of Hays, Kans., sewage treatment plant in the hope that the nesting birds will reduce the *Psychoda* population. (Photo courtesy *Hays* (Kans.) *Daily News*.)

the diet of most other birds includes more seeds and less insects.

An attempt is being made, therefore, to attract wrens to take up residence at the plant so that they will keep down the fly population. The means of providing housing for enough birds to be effective are simple and practically without cost. The houses (Figure 1), made from dried gourds grown on the plant grounds, are hung from trees, fences, and other suitable supports on and close to the plant grounds. The gourds are decorated in bright colors or left in their natural hue, but are protected from weathering by enameling or varnishing them. A 7/8-in. diameter entrance hole will admit wrens and exclude other birds. Cleaning of the houses is simplified by cutting a large hole for that purpose in the bottom and then wiring the cutout back in place for the nesting season.

The gourd bird houses have attracted much attention locally and a considerable quantity of plant-grown gourd seed has been packaged and given away to visitors. Whether or not the wren enlistment effort gets results in the filter fly control program, it has certainly proven to be a wonderfully successful venture in the realm of public relations.

TIPS AND QUIPS

Sewer Blast Cause

A three-man engineering committee investigating a sewer blast that occurred in Cleveland, Ohio, on September 10, 1953, killing one person and injuring 64 others, besides doing damage estimated as high as $6,000,000, has indicated the primary cause of the blast as having been flammable industrial wastes, or gasoline leakage from

filling stations, or both. The findings were submitted in an 84-page report to Cuyahoga County and the cities of Cleveland and Lakewood, Ohio, by the special committee comprising professors George E. Barnes, George W. Blum, and Leon W. Weinberger, all of Case Institute of Technology.

According to the report, the entire district is over an old natural gas field and leakage from the abandoned wells has long caused an odor or nuisance, petroleum seeps underground from the native shale underlying the area, spillage or leakage of flammables may have occurred, and potentially hazardous industrial wastes enter the sewage flow every day from the 194 establishments in the district using flammables. The report recommends elimination of the nuisances and hazards from the old gas wells and that the resources of the city be organized to improve the sewage and industrial waste disposal systems.

Flush Tank Elimination

Flush tank manholes are gradually disappearing from Kansas sewer systems according to a panel discussion during the recent 1954 annual joint meeting of the Kansas Sewage and Industrial Wastes Association and the Kansas Section, American Water Works Association. The discussors pointed out that these devices, besides being unnecessary, are potentially dangerous to the water system, waste precious water, and add unnecessarily to the hydraulic load at sewage treatment plants.

Off-Peak Sewage Discharge

Glendale Center, claimed to be planned as the largest shopping and community center to be constructed in Indiana, will utilize an uncommon method of disposing of its liquid wastes. Located about 8½ mi. northeast of downtown Indianapolis, the Center will house approximately 45 air-conditioned stores, including a branch of Indianapolis' oldest and largest department store.

One of the major problems in developing a modern shopping center is in making adequate provision for sanitary sewage disposal. The sewage requirements of the Center actually will be less than one-half of the demand which would have been created by a typical residential development covering the same area. For example, the 45-acre Center will have a maximum daily discharge of 112,000 gal. of sanitary sewage, occurring on special sale days and at Christmas time. Normal daily flows would be about 67,500 gal. By contrast, a typical residential development of the same acreage would develop 247,000 g.p.d. of waste.

However, even the discharge of 112,000 gal. during a normal day would upset the existing facilities. To prevent this from happening, Glendale will discharge its sanitary sewage between the hours of midnight and 5 AM, when home water consumption is a minimum. To achieve this, the developers will build a sewage impounding reservoir of 225,000-gal. capacity.

As another safeguard to protect the municipal sewage system during rainy and stormy seasons, automatic controls will be installed to prevent the pumping of normal waste from the Center into the sanitary system at such times. Storm-water and drainage systems of the Center will be completely separate from the sanitary system.

Texas Operator Certification

During 1953 the Bureau of Sanitary Engineering, Texas State Department of Health, received a total of 301 applications for sewage works operators' certificates of competency and issued 303 such certificates. The numbers of each grade of certificate issued during

1953 and in force on August 31, 1953 were as follows:

Certificate	No. Issued	No. Valid
Grade A	2	30
Grade B	41	90
Grade B renewal	7	—
Grade C	173	553
Grade C renewal	80	—

Infiltration Control Data Wanted

All who are interested in and who wish to contribute to the improvement of sewer construction practice again are urged to respond to the questions outlined by the Committee on Infiltration Control Practice of the Pacific Northwest Sewage and Industrial Wastes Association (see THIS JOURNAL, **26**, 1, 27; Jan.; 1954). The Commitee hopes to develop a report of practical use to all concerned, and will furnish a copy to each contributor.

Steel Structures Painting Manual

Under the title "Good Painting Practice," the first of two volumes of the "Steel Structures Painting Manual" was recently published by the Steel Structures Painting Council, 4400 Fifth Ave., Pittsburgh, Pa. The 432-page volume describes the best current surface preparation and painting practices in various industries. It is a practical encyclopedia of economical and satisfactory painting methods, rather than a technical treatise on paint formulation. Copies may be ordered from the Council at $6.00 each.

Collector's Item

Strange things have been found at sewage plants, but a recent nomination for the strangest comes from John Cornella, Superintendent at Frontenac, Kans. His find?—an octopus; small and dead, but still an octopus. We knew that parts of Kansas had problems because of salt water, but we've always understood that was oil field brines, not sea water!

Gas Explosion in New Manhole

When the contractor's superintendent on a sewer construction job at Oakley, Kans., was blown about 10 ft. into the air with a manhole cover on which he had been standing, gas leakage from a broken utility line was undoubtedly the cause. From the description given by H. A. Janzen, District Engineer of the Kansas State Board of Health, in *Splashings* (Apr., 1954, p. 4), a gas line had been slightly damaged during the construction operations, but the damage was not deemed serious enough to warrant reporting it to the gas company, so the line was backfilled.

Several days later, after the sewer construction was completed, the engineer and the contractor's superintendent thought they smelled gas, but thought that the odor might have been given off from the jointing compound used. The engineer left to contact the gas company and have them check the line for gas.

The contractor's superintendent walked up the line to the next manhole, the last manhole on the line and upgrade from the one where the odor was detected. Standing on the manhole cover, he lighted a cigarette and dropped the match. The lit match, landing close to the pick hole in the cover, started an explosion that lifted the cover and the superintendent some 10 ft. aloft. Luckily, although he "rose to the occasion," he sustained no serious injury from the return trip to terra firma, although he did suffer severe burns about the legs, face, and hands.

Moral: Treat *all* manholes as potential booby traps—*all* the time!

Reviews and Abstracts*

Biological Treatment of Waste Waters Containing Phenol. By I. Sörensen. *K. Fysiogr. Sällsk. Lund. Förh.*, **20,** 9 10 pp.

At the Lund sewage works at Källby, Sweden, sewage, after mechanical treatment and aeration, is passed through a series of four biological oxidation ponds. In the first three ponds the sewage is purified by the action of algae, bacteria, and protozoa. In the fourth pond large numbers of *Daphnia magna* filter the water during feeding and thus remove algae carried over into the final pond. Laboratory experiments were made to determine the effect of waste waters containing phenol on microorganisms in the oxidation ponds. In addition to phenol these waste waters also contained potassium, sodium, and iron and were strongly acidic. The waste waters were added in concentrations of 1, 2, 3, 4, and 5 parts per 2,000 to cultures of algae and *Daphnia*. With concentrations below 3 parts per 2,000 there was little alteration in the *p*H value, but at 3 parts per 2,000 and higher the *p*H value was considerably reduced. No decomposition of phenol or formation of nitrate occurred. In cultures containing 1 to 2 parts per 2,000, the numbers of algae increased, but all *Daphnia* were killed in 10 to 12 days. With 3 to 5 parts per 2,000, the numbers of algae decreased rapidly; with 3 parts per 2,000, all *Daphnia* were dead in four days and with higher concentrations in one day.

In another series of experiments the effect of the same concentrations of waste water on *Daphnia* alone was investigated and similar results were obtained. In a final series of experiments sewage containing 6 parts per 2,000 of the waste waters was stirred for four days, corresponding to the period of detention in the first three ponds, and was then mixed with water to give a concentration of 3 parts per 2,000 and added to a culture of algae and *Daphnia* in water from the fourth pond. After 10 days all *Daphnia* were dead.

These experiments indicated that the presence of phenolic waste waters, at least in the concentrations used, had a strong toxic action on the organisms taking part in the purification of sewage. The highest permissible concentration of waste waters which will not reduce the *p*H value below the point of tolerance of the organisms is 4 parts per 2,000. It is thought that the waste waters were also toxic to at least some bacteria, as no decomposition of phenol or formation of nitrate was observed. Also, that the gradual addition to the oxidation ponds of phenolic waste waters might encourage the development of organisms which could withstand these conditions and could decompose phenol.

W. P. A.

Sewage Treatment: Imhoff Tanks. By M. V. Suryaprakasam. *Jour. Inst. Eng.* (India), **31**, 65 (June, 1951).

This is a presentation of theory, design, and operation of Imhoff Tanks for primary treatment of sewage. Subjects covered are yardsticks for measurement of sewage purification, theory of sedimentation and digestion, design of various compartments and sludge drying beds, gas collection and utilization, and operational hazards.

In countries like India, which are tropical in climate and do not manufacture machinery required, Imhoff tanks are suitable because they do not require complicated mechanical equipment and are easy to operate. It is clearly brought out that the sedimentation compartment has to be designed on surface loading

* Please send to Federation headquarters all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in This Journal. Publications of public health departments, stream pollution control agencies, research organizations, and educational institutions are particularly desired. Address such material: Federation of Sewage and Industrial Wastes Assns., 325 Illinois Bldg., Champaign, Ill.

rate and the depth of the tank on economy of construction and efficiency of performance. The volume of the digestion zone depends on the temperature, the quality, and the quantity of sludge to be treated. For Indian temperatures a capacity of 1.0 cu. ft. per capita is ample. In cold regions (where the average temperatures are below 60°F.) the digestion capacity is dependent on the time required for proper digestion at the low temperatures. Scum and neutral zones have to be invariably provided. Dried sludge has manure value and can be used as a soil conditioner. W. P. A.

Coagulants from Coal Ashes. By Jerzy Gańczarczyk. *Gaz, Woda i Tech. Sanit.*, **27**, 292 (1953).

The average chemical composition of ashes from Silesian coal is reported as follows: SiO_2, 41%; Al_2O_3, 22%; Fe_2O_3, 12%; CaO, 12%; and MgO, 6%. These ashes were processed into coagulating materials by grinding, activation with H_2SO_4, drying, and ageing. The effectiveness of 9 such coal ashes as coagulants is reported. Reported results for the best activated ash coagulants showed that dosages of 220 to 250 mg. per liter were needed to reduce the color of a given water from 60 to less than 5 mg. Pt per l., the permanganate demand from 10 to less than 3.5 mg. O_2 per l., and the pH from 7.4 to about 6.5; whereas 60 to 80 mg. per l. of alum resulted in a reduction in color to 5 mg. Pt per l., permanganate demand to 6 mg. O_2 per l., and pH to about 6.5. Increasing the flocculation time from 15 min. to 30 and 45 min. resulted in better removals or in a lowering of coagulant dosages. Although the dosage requirements of the activated ash were 3 times those of alum, the volume of sludge was only $\frac{1}{3}$ of that with alum coagulation. Where alum is expensive the author proposes that this waste material be used in coagulation. Conrad P. Straub

Purification and Utilization of Dairy Wastes by Overhead Irrigation of Meadows and Arable Land. By J. H. A. Schaafsma. *Landbouwkundig Tijdschrift*, **65**, 203 (Apr., 1953).

Since 1924 the waste of potato flour has been sprayed on cultivated land with good results. The author, representing the Ministry of Agriculture, has made a survey concerning the volume and strength of the dairy wastes in Holland, particularly in respect to nitrogen, phosphorus, and potash in the wastes. A summary regarding the nitrogen content of the wastes of different types of industries was as given in Table I.

Particular attention is paid to reducing the losses in the industry. As an illustration, the figures in Table II are given. W. Rudolfs

TABLE I.

Industry	N (p.p.m.)	Vol. (g.p.d.)	N (kg./day)
Cheese[1]	61.1–66.8	1,325– 1,850	3.3–4.3
Cheese[2]	10.8–45.8	2,650– 9,300	1.4–16.0
Butter[2]	13.0–14.2	4,000– 8,000	2.0–2.8
Milk products[2]	4.1–21.0	26,500–80,000	4.1–63.0

[1] Separate system.
[2] Combined and cooling water.

TABLE II.

Location	Before			After		
	N (p.p.m.)	Flow (g.p.d.)	B.O.D. (kg./day)	N (p.p.m.)	Flow (g.p.d.)	B.O.D. (kg./day)
Plant 1	45.8	9,300	245	13.6	9,300	63
Plant 2	38.6	3,900	78	14.9	3,900	36

Utilization of Cannery Fruit Waste by Continuous Fermentation. By S. L. Adams. *Bull. Wash. State Coll.*, No. 207, p. 1 (1950).

Fermentation of waste waters from canning of pears, peaches, apples, cherries, and maraschino cherries has been studied, and substances which increase the speed and efficiency of the process have been determined. In the case of pears, it was found that 90 per cent of the sugar is converted to alcohol in 30 hr. by the action of *Saccharomyces cerevisiae* No. 90, and that this time could be reduced to 10 hr. by the addition of nitrogen. Dried residue can be used as a feedstuff for sheep.

W. P. A.

Detergents and Their Effect on Biological Oxidation. By C. Lumb. *Surveyor*, 112, 893 (1953).

Concentrations of anionic and nonionic detergents from 20 to 90 p.p.m. were added to sewage which was treated in laboratory-scale trickling filters and activated sludge tanks. The results indicated that the performance of both treatment processes was adversely affected by both types of detergents. The effects of the two different detergent types were additive when a mixture was present. Either type produced a tendency for the treated effluents to froth, due to incomplete decomposition of the detergents by the treatment processes. The adverse effects of detergents could be largely overcome by increased capacity of trickling filters, but activated sludge was permanently inactivated to some extent by one of the anionics tested. The effects became significant when their concentration reached about 10 p.p.m. in the settled sewage, which corresponds to about 20 p.p.m. in the raw sewage. Above that level, the effects increased sharply. M. C. Rand

A Simple Automatic Sampler for Water. By R. Wilkinson and R. Briggs. Reprinted from *Chem. and Ind.* (Brit.), p. 886 (1953).

A detailed description of an automatic sampler is given. It is independent of an electrical current, requiring only a battery and a spring clock. Each sampling unit is complete, and the apparatus described consists of two racks each containing 12 sampling units, for the taking of hourly samples during a period of one day. It has been successfully used on a river bank in the open with a suction lift of 2 or 3 ft. In tests, a sample has been lifted to a height of about 25 ft., although it is advisable to work at the lowest convenient head. R. E. Anderson

Waste Water Reclamation in Relation to Ground Water Pollution. California State Water Pollution Control Board, Sacramento, Calif. 124 pp. (1953).

For a period of 28 months the Sanitary Engineering Research Project of the University of California investigated the reclamation of water from sewage by spreading. The principal objectives of the investigation included a study of spreading on field plots to determine the following:

1. Rate of percolation of industrial waste and sewage effluents on different soil types during spreading operation.
2. Optimum spreading and resting periods to obtain maximum rates of percolation.
3. Extent and degree to which mineral and organic matter (including bacteria) in the water will penetrate different soils.
4. Changes in mineral and organic characteristics of both soil and water at different depths during percolation.
5. Degree of treatment necessary for industrial waste and sewage to obtain satisfactory percolation rates, protection against contamination and nuisance (odors, etc.), and protection of underground water supply.
6. Cost of spreading, as far as this is incidental to research.

A site was selected adjacent to the sewage treatment plant at Lodi, Calif. Eight circular spreading basins, 19 ft. in diameter, were constructed with sheet metal dikes. Four of the basins were equipped with sampling facilities so that samples of the percolating liquid could be collected for bacteriological and chemical analyses at 1, 2, 4, 7, 10, and 13 ft. below the ground surface. Spreading was studied with three liquids: fresh water, sewage treatment plant final effluent having a B.O.D. of about 10 p.p.m., and settled sewage with a B.O.D. of about 100 p.p.m.

A number of operating variables were

studied to determine the conditions leading to maximum percolation rates and minimum contamination or pollution of the ground water. These variables included:

1. The nature of the liquid being spread.
2. The length of the spreading period.
3. The length of the resting period.
4. The effect of surface treatment such as spading, the use of a sand cover, and the application of a soil stabilizer.

After the termination of the field study the installations were dismantled and a careful study made of soil conditions and sampling devices. It was concluded that:

1. A bacteriologically safe water can be produced from settled sewage or from final effluent if the liquid passes through at least 4 ft. of soil.
2. A water of satisfactory chemical quality can be produced from settled sewage or from final effluent, providing high concentrations of undesirable industrial wastes are not included in the raw sewage.
3. A highly treated sewage plant effluent must be used for spreading in order to obtain high rates of percolation.
4. A percolation rate of at least 0.5 acre-ft. per acre per day can be expected when spreading a final effluent on a Hanford fine sandy loam.
5. The optimum method of spreading basin operation is to spread continuously for about a month, preferably with a liquid containing large amounts of organic matter, then to allow the basin to rest until the moisture content is reduced to about the permanent wilting point. Thereafter, cultivation of the dry soil seems desirable. Following this preliminary treatment, continuous application of a final effluent may be carried on for as long as six months. Resting and cultivation may then be repeated.
6. Mosquitoes in spreading basins will create a nuisance and health hazard unless control measures are adopted. If algal odors are pronounced, the control of algae also may be necessary.
7. Further investigations of percolation of sewage in different soils, and of phenomena associated with the movement of water into such soils, are needed in order to generalize the foregoing conclusions reached as a result of this study with Hanford fine sandy loam. H. P. O.

Water Pollution Report, Walnut River Basin. Division of Sanitation, Kansas State Board of Health, Lawrence, Kans. (1952).

Volume I of this two-volume work is a summary report of the division's survey on this river basin. Although important progress has been made in recent years in disposing of oil field brine, there are many obstacles established by tradition to overcome in abating pollution caused by practices which have been followed since before oil pollution laws were adopted in Kansas.

An industrial waste which seriously affects the streams of the valley is that produced by the oil refining industry. Until recently, knowledge of refinery waste treatment methods has been inadequate. However, between 1945 and 1952 sufficient work has been done on this type of waste to develop adequate methods of treatment.

Oil field, industrial, and municipal wastes, the progress made in treating and disposing of them, and the damages to ground and surface waters caused by them are discussed in detail. Several municipal water supplies were abandoned because of brine pollution shortly after oil was first found in the basin (1915); no public water supplies were directly affected at the time of the survey.

Volume II is the detailed technical report of the same survey. The conclusions of this section are summarized as follows:

1. The Walnut River basin is seriously polluted by oil field brines, industrial wastes from oil refineries, and municipal sewage.
2. Excessive oil field brine pollution comes from 9 major areas in the basin, along the Walnut, Whitewater, and West Branch of the Walnut Rivers, and 11 tributaries.
3. Of the municipal sewage treatment plants, only three are adequate for the present loads.
4. None of the refineries have satisfactory treatment facilities. One refinery at Augusta has, because of a limited supply of processing water, been forced to adopt a treatment process for its wastes so that the waste water can be re-used.
5. Until the pollution problem is corrected there is little chance that further

industrial development can occur in the basin where the industry may require considerable quantities of fresh water.

Recommendations for abating pollution include elimination of all brine ponds and brine discharges to surface watercourses; dike protection of all oil storage tanks against spillage; special construction of all pipe line stream crossings; new or reconstructed treatment plants at five municipalities; and oil separation and secondary biological treatment installations at several petroleum refineries.

Both volumes are available, but as loan copies only, from the publishing agency.

H. P. O.

Studies on the Disinfection of Sewage Using Sub-Chlorine Demand Dosages. By W. Hermanowicz and W. Dożańska. *Gaz, Woda, i Tech. Sanit.*, **27**, 255 (1953).

The procedure followed in these studies consisted of the collection of a grab sample of Warsaw sewage (8 AM); settling for 2 hr.; determination of the chlorine demand (15-min. contact time, residual of 0.1 mg. per l.), which ranged from 3.5 to 7.5 mg. per l. of chlorine; chlorination of the wastes; and determination of bacterial reductions at temperature of 15°, 20°, and 25°, and contact times of 5, 15, and 30 min. All samples collected for bacterial analysis were placed in bottles containing 0.5 ml. of 10 per cent Na_2SO_3 for dechlorination. Bacterial dilutions were prepared and inoculations made in Eijkman bullion and agar, which were incubated at 37° C. and read at 24 hr.; *E. coli* determinations were made using Endo, Simons, Clark, Voges-Proskauer media, and reaction with methyl red. Membrane filters also were employed in the *E. coli* determinations on Endo agar. Thirty-eight series of tests were made in which more than 1,000 plates were inoculated. The results indicated that removals of 99.9 per cent of the bacteria could be obtained following 30-min. contact at 15° C. at a dose equal to 40 per cent of the chlorine demand, at 20° C. at 40 per cent of the chlorine demand, and at 25° C. at 20 per cent of the chlorine demand. Initial bacterial counts in the raw sewage ranged from 300,000 to 2,000,000. Other observations given by the authors included the following: (a) longer contact time at lower dosages gave as good results as higher dosages at short contact times; (b) dosages as low as 10 per cent of the chlorine demand dose gave substantial removals (to 80 per cent); and (c) oxidation-reduction potential measurements at low chlorine dosages showed that the E_h value increased with increased removals of bacteria. After analyzing their data the authors developed a first-order equation which related the per cent bacterial reduction and the time of contact. This equation was of the form

$$K = \frac{2.303}{t} \log \frac{100}{100 - Z}$$

in which K equals the rate of bacterial reduction, t is the time of contact, and Z the observed percentage removal. A table of K values is given for various temperature and chlorine dosages (expressed in per cent of the chlorine demand).

Conrad P. Straub

Sludge Digestion at Birmingham Works. *Surveyor*, **113**, 47 (Jan. 16, 1954).

This is a rather detailed account of the results realized in digestion of sewage sludges at five different works in the city of Birmingham, England. Gas yields and reduction of organic matter, as well as the B.O.D. and ammonia content of the sludge liquors, are reported. The sludges digested at the several plants differ in character, containing various proportions of solids of industrial origin, waste activated sludge, and humus. Accordingly, digestion practice varies from plant to plant. The effects of these variations upon the results obtained are considered in the report.

M. C. Rand

Report on a Systematic Study of the Algae of Sewage Oxidation Ponds. By Paul C. Silva and George F. Papenfuss. Publ. No. 7, State Water Pollution Control Board, Sacramento, Calif. (1953).

Use of oxidation ponds to provide secondary sewage and waste treatment is currently finding wider use and acceptance. Aeration in such ponds is commonly by algae. This paper presents field studies, to amplify laboratory studies of the process.

Ten localities, including many ponds, were surveyed. Three handled only domestic sewage, the others treat milk or other wastes as well. About 20 photo-

synthetic and two colorless genera were identified and studied. Many of the species are illustrated, and their relative as well as absolute abundances are given. An evaluation of their ecological status and their behavior aside from aeration is discussed, especially the fact that many such species utilize organic compounds in nutrition. Thus they may be of much more use in purification (mineralization) than is commonly realized. It is pointed out that a study of algae as complementary to bacteria is especially needed. Algal dominance and succession is well shown in the ponds, but no clearly defined pattern was found, and no explanation of causes is advanced; further work is necessary. Relation of pond design and layout, loading and operation, to performance and algal population is considered.

The paper is a carefully considered presentation with 50 references as a background. JAMES B. LACKEY

Algal-Bacterial Symbiosis in Sewage Oxidation Ponds—Third Progress Report. BY HAROLD B. GOTAAS AND WILLIAM J. OSWALD. Inst. of Eng. Research, Univ. of Calif., Berkeley, Calif. (Dec. 31, 1952).

This third report emphasizes the increasing cost of adding oxygen in any sewage or waste treatment process. It also reiterates that oxygenation by photosynthesis has been neglected. Besides oxygenation, algae may use organic compounds in the substrate, may tie up substantial amounts of B.O.D. in the algal cells, may serve as food for insect larvae, and may influence purification because of symbiotic relations with purification bacteria.

The report treats three phases of work. In the first, aseptic system culture tubes holding 1,200 ml. produced, among other results, mathematical formulas showing the relationship between oxygen production and the volume of algal cells; oxygen production as related to detention time; proof that intense illumination eventually destroyed chlorophyll. Light intensity, light periodicity, and illumination frequency are under study with these culture tubes, as well as effects of strengths of sewage, and temperature. Pure cultures of algae and bacteria are used; the number of these now includes 11 strains representing 7 species of 4 genera of algae and 24 strains of 10 genera of bacteria.

In the second phase, symbiocon tubes, like the aseptic system culture tubes except sealed to external air, demonstrated a mutual growth benefit between *Euglena gracilis* and sewage bacteria, a not hitherto shown relationship. Such sealed cultures gave preliminary information on pH, D.O., and B.O.D., which is being further investigated. *Chlamydomonas* (3 species) was also used with bacteria and showed a different but inconclusive growth picture.

In the third phase a pilot-scale oxidation pond was operated after July 1, 1952. Its effluent can be centrifuged and the supernatant recirculated through the pond; recirculation rate, depth, and detention period can be varied. Two experimental pond loadings yielded some tentative conclusions. B.O.D. removal is 80 per cent or better, and the pond responds well to operational principles established in the laboratory.

The whole report shows careful work planning and accounting for all possible variables. Some natural hesitancy to accept preliminary results is evident (this is, after all, a progress report), but some results are definite. It has been shown that certain algae can be grown in fresh, strong domestic sewage. Their highest rates of oxygenation occur at short detention periods; the highest rates of aerobic bacterial growth should be concurrent. Continuous high-rate treatment of domestic sewage has been accomplished, resulting in conversion of putrescible organic matter into algal cell material and a stable highly oxidized liquor of low B.O.D. Variables such as detention time, intensity of illumination, symbiosis of algal with bacterial species, and precision controls have been or are being evaluated.

JAMES B. LACKEY

Laboratory Studies on the Coagulation of Spent Sulfite Wastes. BY JERZY GAŃCZARCZYK AND JERZY DOMAŃSKI. *Gaz, Woda i Tech. Sanit.*, **27**, 302 (1953).

The wastes investigated had the following range in chemical composition: pH 6.8 to 7.3, total solids 827 to 1,720 mg. per l., loss on ignition 575 to 1,145 mg. per l., permanganate O_2 demand 385 to 1,087 mg. per l., calcium 89 to 179 mg. per l. Ca, iron 24 to 162 mg. per l. Fe. Various coagulants were used and the results obtained

with each being summarized as follows:

Alum—dosage 2,500 mg. per l. $Al_2(SO_4)_3 \cdot 18H_2O$. Color reduced to 200 mg. per l. Pt, permanganate demand to 73 mg. per l. O_2, pH 4.8. Correcting for pH with 400 mg. CaO reduced the color to 60 mg. per l. Pt, O_2 demand to 70 mg. per l. O_2, and the pH was increased to 7.0. The sludge contained 99.3 per cent moisture and 36,808 mg. per l. of sludge (dry weight, 105° C.).

Ferrous sulfate—pH raised to 10.9 to 12.1; dosage 1,800 mg. per l. $FeSO_4 \cdot 7H_2O$ and 800 mg. per l. CaO. Color reduced to 100 mg. per l. Pt, O_2 demand to 44 mg. per l. O_2, and pH raised to 11.1. The sludge contained 99.4 per cent moisture and 27,859 mg. per l. of sludge (dry weight, 105° C.)

Ferrous sulfate and Cl_2—pH raised to 8.5 to 11.8; dosage 1,600 mg. per l. $FeSO_4 \cdot 7H_2O$, plus the required amount of chlorine, plus 1,000 mg. per l. CaO. Color reduced to 150 mg. per l. Pt, O_2 demand to 75 mg. per l. O_2, and pH increased to 11.0. The sludge contained a moisture content of 98.9 per cent and 23,016 mg. per l. of sludge (dry weight, 105° C.)

Milk of lime—dosage 6,000 mg. per l. CaO. Color reduced to 180 mg. per l. Pt, O_2 demand to 40 mg. per l. O_2, and pH raised to 12.3.

Milk of lime and saturation with CO_2—dosage 4,500 mg. per l. CaO. Color reduced to 100 mg. per l. Pt, O_2 demand to 38 mg. per l. O_2, and pH was 7.0. The sludge contained 86.3 per cent moisture and 172,654 mg. per l. solids (dry weight, 105° C.)

Milk of lime and $CaOCl_2$—dosage 4,500 mg. per l. CaO and 100 mg. per l. $CaOCl_2$. Color reduced to 150 mg. per l. Pt, O_2 demand to 30 mg. per l., and pH raised to 12.2. The sludge contained 86.1 per cent moisture and 129,630 mg. per l. solids (dry weight, 105° C.)

Increasing the flocculation time from 15 to 30 min. lowered the color by 10 to 20 per cent, the O_2 demand by 10 to 30 per cent, or permitted a 15 per cent lower dosage of chemicals. The authors indicate that lime treatment, because of the possible regeneration by calcining and re-use of lime, might be the most satisfactory process in view of the large sludge volumes for disposal. CONRAD P. STRAUB

Treatment of Sulfate Cellulose Process Wastes. By HALINA SIEKIERZYŃSKA AND JERZY ZIELIŃSKI. *Gaz, Woda i Tech. Sanit.*, **27,** 324 (1953).

Following a description of the sulfate process, the authors give the results of laboratory studies on the treatment of these wastes by coagulation with lime, sulfuric acid, and ferrous sulfate and $CaOCl_2$. The data presented indicate that coagulation with lime will result in a 50 per cent reduction in the O_2 demand (permanganate), with H_2SO_4 in a reduction of 50 to 80 per cent, and with $FeSO_4 \cdot 7H_2O + CaOCl_2$ in a reduction of less than 50 per cent. CONRAD P. STRAUB

Water Pollution Research 1953. H. M. Stat. Off., London, Eng. 62 pp. (1954); available in U. S. through British Information Services, 30 Rockefeller Plaza, New York 20, N. Y.

Included are the reports of the Water Pollution Research Board and the Director of Research, describing the work of the Water Pollution Research Laboratory during 1953. Results of investigations of interest were as follows:

Water—Currently used water treatment processes will not remove all radio-isotopes likely to be present in a water contaminated as a result of an atomic explosion, although a comparatively high proportion of some isotopes would be removed.

Sewage—Further work has been done on the relation between the efficiency of a percolating filter treating sewage and the rate of movement of the distributor. There seems to be an optimum rate of movement for a distributor, which (for a circular filter) may be lower than that commonly found at sewage works. For example, in four large circular filters at Birmingham the optimum rate of distributor rotation appears to be 1 rev. in 15 to 30 min. With this rate, the filters become much less ponded, and the quality of the final effluent is much better, than when the distributors revolve more rapidly.

One of the effects of reducing the rate of travel is usually to increase the extent of nitrification, often by a considerable amount. During one period of three months the concentration of oxidized nitrogen in effluent from a pair of filters with distributors rotating once in 30 min. was more than twice as great as in effluent from

a similar pair of filters on which the distributors rotated once in 1 to 5 min. The reasons for these differences are not known, but some preliminary work is described on the movement of water through experimental filters.

Surface storm drainage from a housing project also was studied. Suspended solids varied from 30 to 1,000 p.p.m., but the B.O.D. rarely exceeded 20 p.p.m., usually being about 7 p.p.m. except at the beginning of storms.

Industrial Wastes—Acclimatization of the organisms of a biological filter to metallic cyanides makes possible toleration of concentrations of the order of 100 p.p.m. In fact, some metallic cyanides (potassium, and zinc and cadmium complexes) can be destroyed in a trickling filter without addition of sewage or other nutrient. The economies and convenience of biological destruction of electroplating and steel hardening wastes are being compared with those of the chemical methods currently used.

Segregation of retort-house liquor from gas plant wastes and treatment of hot gas in electrostatic detarrers allowed addition of 2.5 per cent by volume of spent gashouse liquor without deterioration of sewage treatment.

Anaerobic fermentation of cotton kiering "black liquor" for four days at 30° C. reduced the B.O.D. by about two-thirds. The gas evolved contained nearly 70 per cent methane.

Effects on fish—Variations in the numbers of fish present in an open channel carrying the effluent of the Colne Valley sewage works seem unrelated to the chemical changes in the effluent. Toxicity studies by the laboratory have shown, however, that the precise level of oxygenation of a contaminated water may be of great importance, even though much higher than in itself would cause asphyxiation.

Thames Estuary survey—A large proportion of the work of the laboratory was concerned with study of conditions in the Thames Estuary. The main effort was concentrated on the sources and rates of deoxygenation and reoxygenation.

H. P. Orland

Annual Report, Commissioner of Public Works, Fitchburg, Mass., for 1952.

This report covers streets, water, sewers, and sewage disposal. W. Lamothe, operator of the sewage works, reports that in 1952 the treatment works handled an average flow of 4.12 m.g.d. (or 97.9 g.p.c.d.) The detention period in the Imhoff tank settling chambers averaged 5.25 hr. The skimmings averaged 3 cu. ft. per day. The trickling filters treated an average of 2.24 m.g.a.d. The nozzles cleaned per day averaged 10.5. The population contributing was estimated at 42,000. The total volume of sludge (Imhoff and secondary) removed was 980,000 gal., of which 610,000 gal. was delivered to air drying beds and the balance to lagoons. The sludge beds were cleaned twice. No analyses are reported. The operator states that the plant delivered a highly purified effluent to the North Branch of the Nashua River.

Langdon Pearse

Public Health Engineering Achievements and Problems. By E. H. Vick. *Surveyor*, **113**, 29 (1954).

This presidential address to the Institution of Sanitary Engineers is written from a British standpoint. After discussing general trends in sanitation, particularly in sewerage and drainage, Mr. Vick comments on the lowering of standards in sewerage practice due to lack of funds. Problems have also arisen due to replanning.

The London County Council points to brick sewers 100 years old, which need enlarging to carry present-day flows. Also, many sewage works are overloaded and must be modernized or enlarged.

Research on the sludge problem had developed a feeling that sludge should be returned to the land, yet digested sludge is only of moderate value as fertilizer, lacking potash. However, he considers activated sludge has greater possibilities, despite its large volume. The London County Council has been experimenting on freezing, thawing, and subsequent dewatering of activated sludge, but has yet to demonstrate the economy of the procedure.

On April 1, 1954, London County Council was to be empowered to control the industrial wastes entering its sewers, having received authority in 1953 to regulate the quality, quantity, and rate of discharge, by agreement with the industries, where information has been obtained.

Mr. Vick advocates continued research and adequate training of young sanitary

engineers, as well as the coordination of various groups interested in public health.

LANGDON PEARSE

Annual Report Bureau of Sewers, for the Year Ending December 31, 1951, City of Worcester, Mass.

Worcester has a total length of sewers (to 1952) of 499 mi., of which 226.56 are sanitary, 192.3 are surface, and 70.22 are combined. In 1951 there were 36,668 house connections.

In 1951 the sewage treatment plant handled 10,066.2 m.g. at a cost of $9.51 per m.g. and $0.501 per capita served (est. 190,000), with an average removal of 80.8 per cent B.O.D. and 86.4 per cent suspended solids. The average pH of the raw sewage varied from 6.7 to 7.0. 867,808 gal. of waste pickling liquor from industry were deposited on the old sand filters. The total sludge removal from the Imhoff tanks was 4,152.5 tons of dried material, containing in 45.77 per cent volatile, 1.59 per cent iron as Fe, and 1.45 per cent ammonia. The detention period in the Imhoff tanks was 2.4 hr. The trickling filters were dosed at 2.85 m.g.a.d. (new) and 2.82 m.g.a.d. (old). The final clarified effluent ranged from 1.07 to 1.34 p.p.m. of nitrite-nitrate content.

Air-dried sludge was removed from the beds by contract for $0.87 per cu. yd.

The report contains tables on cost, and analytical data. LANGDON PEARSE

Studies of Bathing Water Quality and Health. By ALBERT H. STEVENSON. *Pub. Health*, **43**, 5, 529 (1953).

Studies to determine what quality of bathing water would be acceptable under local conditions were made on Lake Michigan at Chicago, Ill.; the Ohio River at Dayton, Ky.; a nearby swimming pool in the same area; and Long Island Sound at New Rochelle and Mamaroneck, N. Y. The results demonstrated that an appreciably higher over-all illness incidence may be expected in the swimming group over that in the nonswimming group, regardless of bathing water quality. Some 100 per cent higher illness incidence is shown in the group under 10 years than for those over 10 years of age. A significant increase in illness incidence was observed among swimmers using the South Beach at Chicago on three selected days when the water had an average coliform content of 2,300 per 100 ml. A second instance of positive correlation was observed in the Ohio River study where swimming in water having a median coliform density of 2,700 per 100 ml. appears to have caused a significant increase in gastrointestinal illnesses. Indications are that some of the strictest bacterial quality requirements currently set for natural bathing waters might be relaxed somewhat without significant detrimental effect on the health of the bathers. H. P. ORLAND

BOOKS, REPORTS, AND PAMPHLETS

Proceedings 59th Annual Public Works Congress. Amer. Pub. Works Assn. 88 pp. Price, $5.00 (1953).

Contains the papers of the Congress held at New Orleans, La., in October, 1953. Included are three papers of a symposium on composting as a method of garbage disposal, one on principles of design and operation of municipal incinerators, and a symposium on intergovernmental relations in public works, including the place of sewage treatment in the organizational structure.

Proceedings of the Illinois Association of Sanitary Districts—29th Annual Report, 1953. 59 pp. (1953).

1953 Annual Report. Interstate Sanitation Commission, New York, N. Y. 33 pp.+maps and appendices (1954).

Firing with Sulfite Waste Liquor. Rep. No. 8, Comm. on Coordination of Research, Amer. Paper and Pulp Assn., New York, N. Y. 7 pp.+13 figs. (1953).

A reprint of a paper by G. Edling read at the Annual Meeting of the Norwegian Steam Users' Assn., Mar. 24, 1953.

Shinnecock Bay—Mecox Bay Drainage Basin. Suffolk County Survey Series Report No. 4, N. Y. State Water Poll. Control Board, Albany, N. Y. 21 pp. +maps (1953).

Book Review

Stadtreinigung. Edited by W. Kohlschütter, W. Schwenke, and A. D. Stahlkopf. Verlag für Technik und Kultur, Berlin-Charlottenburg, Germany (1953).

This German book on municipal sanitation is available in loose-leaf form and comprises five main divisions: A. Sewage in General; B. Sewer Systems; C. Purification and Utilization of Sewage; D. Disposal and Utilization of Garbage and Trash; and E. Air Purification.

At present, Division C only has been published, containing individual sections CA, CB, CC, CE, and CF, which are offered separately in loose-leaf form.

CC I-III. Biological Purification of Municipal Wastes. By Heinz Stahlkopf.

The first 48 pages of this section cover the various types of filters. Standard filters and the different types of high-rate filters, including those of American origin, are described and illustrated. There follows 32 pages covering the activated sludge process and describing the various methods of surface aeration, mechanical aeration, air diffuser systems, and combinations of these types. The discussion of plant loadings includes the process (the Magdeburg P-process) developed by Nolte, which proposes the addition of nitrogen and phosphorus as needed for the treatment of highly concentrated wastes, especially industrial wastes containing phenol. The average demand of N and P recommended by Meinck is 1 mg. of N for 20 mg. B.O.D. and 1 mg. of P for 75 mg. B.O.D., compared with 3 mg. of N and 1 mg. of P for 45 mg. B.O.D. recommended in the American literature. The Nolte process allows loading on aeration units up to five times conventional loadings.

Section CC is confined to the purification of the wastes only. Sludge disposal and sludge utilization are discussed in a separate section.

CE. Examples of Existing Treatment Plants. By Heinz Stahlkopf.

This 73-page section gives complete descriptions of eight treatment plants constructed for municipalities ranging from 1,300 to 800,000 population equivalent, including a neutralizing plant for a metal-working industry.

The design data for each plant are explained in detail and supplemented by design drawings, computations, and photographs. The reasons for the selection of the particular design are outlined. Most of the described designs are either partial treatment plants or complete treatment by filters. The design of the largest plant for a sanitary district in an industrial area calls for primary treatment followed by a two-stage activated sludge process (paddle aeration). The first stage allows 2-hr. aeration, followed by settling, the second stage provides 8-hr. aeration and final settling. Digester gas is carefully scrubbed, compressed, and bottled for use in trucks or households.

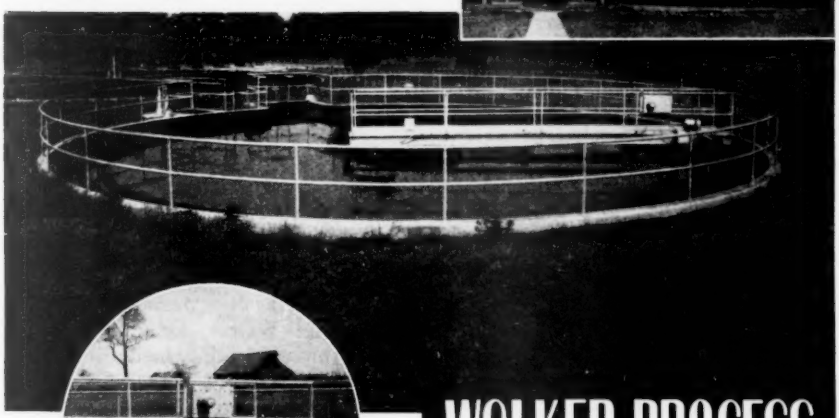
A novel method of polishing plant effluent is mentioned in the description of an institutional plant where the effluent from a primary treatment plant is diluted by fresh water and then conveyed to two fish ponds from 8 in. to 2 ft. in depth. The ponds, stocked with German carp and trout, are expected to yield 0.7 lb. of fish per capita per year.

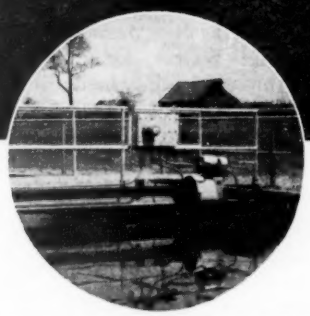
These sections reveal that German engineers prefer mechanical types of aeration by paddle, brushes, etc., to the diffused air methods, which they claim to be too costly to operate. Power recovery from sludge gas for small gas engine-driven air blowers (or pumps), as well as large dual-fuel gas engines as practiced in the U.S.A., seems to be considered less economical than the intricate preparation of bottled sludge gas for use in trucks and households.

Pre-aeration and the great value (economically and technically) of chemical pretreatment of highly concentrated and fluctuating wastes prior to their biological treatment are apparently not recognized as much as in the U.S.A.

[Abstractor's note—The prices for the various sections range from $2.00 to $5.00 each.] Paul A. Uhlmann

Farmington, Mo.
Sewage Disposal Plant uses..





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Tractor Drive Circular Collectors
Floating Cover and HeatX for Digester

The sewage treatment plant at Farmington, Missouri includes a number of Walker Process units.

Tractor Drive Circular Collector mechanisms are installed in both the 44′ diameter primary and 38′ diameter final settling tanks. These rugged units feature a unique simplified tractor arrangement, providing rotational force at the tank periphery.

A four-arm 10″ H Rotoseal rotary distributor delivers 1570 gpm over the 120′ filter bed. A mechanical Neoprene seal and large cast bronze lower thrust bearing add to the trouble-free operation of this unit.

The 39′ diameter Floating Cover on the digester is designed so that no truss or frame work protrudes above the tank. Constant gas pressure is maintained. Ballast and counter weights are suspended below the cover as positive prevention against overturning.

The Walker Process HeatX accomplishes sludge heating outside the digester. This self contained unit includes control panel, burner, hot water tube boiler and shell, and tube exchanger. It operates on natural and sewage gas.

Consulting Engineer:	Charles A. Haskins Kansas City, Mo.
Superintendent:	Frank Zimmer
Chief Operator:	Otha Parker

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Proceedings of Member Associations

LOUISIANA CONFERENCE ON WATER SUPPLY AND SEWERAGE

The 1954 Annual Meeting of the Sewage Works Section, Louisiana Conference on Water Supply and Sewerage, was held at Louisiana State University, Baton Rouge, La., March 10–12, 1954, in conjunction with the 17th Annual Short Course.

Papers presented at the sewage section meetings stressed plant records and public relations, safety practices, plant arithmetic, control tests, operation and maintenance of plant equipment, chlorination, sewer system problems, and grit and sludge disposal, in addition to the regular short course subjects.

Officers elected for 1954–5 were:

Chairman: J. L. Love, Lafayette.
Vice-Chairman: R. L. Lawrence, Alexandria.
Secretary-Treasurer: G. H. West, Lake Charles.

G. H. West,
Secretary-Treasurer

NEW JERSEY SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

Once again a new attendance record was set by the New Jersey Sewage and Industrial Wastes Association at its 39th Annual Meeting, held at the Hotel Traymore, Atlantic City, N. J., March 10–12, 1954. Paid registration was 450, including 67 ladies.

(*Continued on page 270a*)

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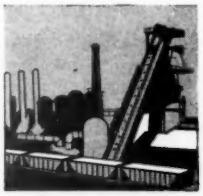
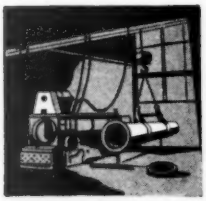
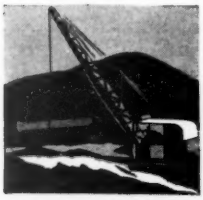


Blast Furnaces



Pipe Plants



Pipe Installations

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Technical papers presented were as follows:

"Instrumentation for Sewage Plant Operation," by I. T. Klein, General Laboratory Supply Co., Paterson, N. J.

"Design and Operation of Experimental Equipment for Biological Treatment of Complex Organic Chemical Wastes," by George Hendee and Louis Tucci, Calco Chemical Div., American Cyanamid Co., Bound Brook, N. J., and Alfred Cherry, Lederle Laboratories Div., American Cyanamid Co., Pearl River, N. Y.

"Industrial Wastes in Municipal Sewers—Flexible or Strict Regulations?" by H. Heukelekian, Professor, and H. Orford, Acting Chief, Department of Sanitation, Rutgers University.

"Cost Studies of Sewage Disposal Systems," by John W. Zelley, New Jersey State Dept. of Health, and Michael S. Kachorsky, Borough Engineer, Manville.

"Organic Wastes Treatment in a Suspended Solids Reactor," by Gordon A. Olson and R. W. Haywood, Jr., Engineering Dept., E. I. du Pont de Nemours and Co.

"The Trend in Quality and Joints for Reinforced Concrete Sewer Pipe," by Hugh Kennison, Chief Engineer, Lock Joint Pipe Co.

"Maintenance of Metering and Control Equipment," by F. L. Sommer, Simplex Valve and Meter Co.

"Treatment of Milk Receiving Plant Wastes," by A. J. Powers and S. Trani, Farm Products Div., The Borden Co.

"Reduction of Paper Mill Pollution Through Recirculation," by E. I. Merrill, Plant Engineer, Johns-Manville Corp., Manville.

As usual, the last morning was devoted to an Operators' Breakfast and Business Meeting, followed by a symposium on "Headaches in Sewage

(*Continued on page 272a*)

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The 23rd Annual Meeting of the Arkansas Water and Sewage Conference, held in conjunction with the Annual Short School at Little Rock, Ark., March 22–24, 1954, set a new high of 213 registrations.

Papers of interest to sewage works personnel included:

"Operating Difficulties with Fixed and Movable Covers," by Marion L. Crist, Consulting Engineer, Little Rock.

"Grit, Scum, and Grease Removal Devices," by Max A. Mehlberger, Consulting Engineer, Little Rock.

"Engineered Planning in Sewerage Improvements," by T. Wilson Clapham, Engineer-Manager, Little Rock Sanitary Sewer System.

"Property Inventory and Records," by M. R. Ulmer, Assistant to Manager, Water and Light Plant, Jonesboro.

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Laboratory Equipment—Bulletin No. 700 gives comprehensive data on many types of laboratory apparatus.—Andrew Technical Service, Chicago 26, Ill.

Thermocouple Wires—Data on thermocouple and extension wires are given in Specification Sheet 307.—Minneapolis-Honeywell Regulator Co., Philadelphia 44, Pa.

Chain—Bulletin 53–56 describes corrosion and abrasion-resistant chain of Z-metal.—Chain Belt Co., Milwaukee 1, Wis.

Lightweight Pipe—Specifications and application data for lightweight, lockseam, spiralweld pipe and fittings are given in Bulletin No. 507.—Naylor Pipe Co., 1230 East 92nd St., Chicago 19, Ill.

Respirator—A single respirator protecting against toxic dusts and organic vapors is described in Bulletin No. 1007–4.—Mine Safety Appliances Co., Braddock, Thomas and Meade Sts., Pittsburgh 8, Pa.

Water Treatment—A new bulletin describes three-stage reactors for softening and clarifying surface and waste waters for re-use.—American Water Softener Co., Philadelphia, Pa.

Pipeline Heaters—Bulletin G. E. A–5095A describes numerous pipeline applications of Calrod tubular heaters.—General Electric Co., Schenectady 5, N. Y.

Liquid Level Indicator—A new liquid level indicator system uses an ultrasonic pulse ranging technique to accurately indicate levels in processing and storage tanks to within 0.01 ft., as well as precisely locate the demarcation line between immiscible liquids.—Bogue Electric Mfg. Co., Paterson, N. J.

Backflow Preventer—Available in all sizes from 1 in. to 16 in., a new backflow preventer automatically maintains a reduced pressure zone between double check valves.—Backflow Engineering and Equipment Co., Los Angeles, Calif.

Sludge Thickening Process—Applicable to controlled continuous thickening of both primary and secondary sludge, the new "Densludge" process is said to eliminate digester supernatant liquor and reduce sludge volume up to 50 per cent.—The Dorr Co., Barry Place, Stamford, Conn.

Plug Valve—Grooved-end lubricated plug valves are available for use with grooved-end couplings on steel and iron pipe. The somewhat flexible connections are particularly suitable for lines subject to vibration, expansion, contraction, and uneven settlement, especially at pumping station connections and viaduct and bridge crossings.—Rockwell Mfg. Co., 400 North Lexington Ave., Pittsburgh 8, Pa.

Flow Regulator Drive—Pneumatically-operated control drive for valves, dampers, feeders, etc., may be operated on a straight-line flow characteristic.—Bailey Meter Co., 1050 Ivanhoe Rd., Cleveland 10, Ohio.

pH Control—Bulletin 340–92 reviews continuous pH recording and control in water treatment, control of chemical reactions, and waste disposal. A separate section on chemical reactions explains pH control in emulsification, electrolysis, neutralization, hydrolysis, biochemical processing, coagulation and precipitation, and bleaching, dyeing and conditioning of fibers and fabrics.—Beckman Instruments, Inc., South Pasadena 1, Calif.

Acid-Proof Cement—New 4-page bulletin describes Staminite acid-proof cement and gives application instructions.—The Robinson Clay Products Co., 65 W. State St., Akron 9, Ohio.

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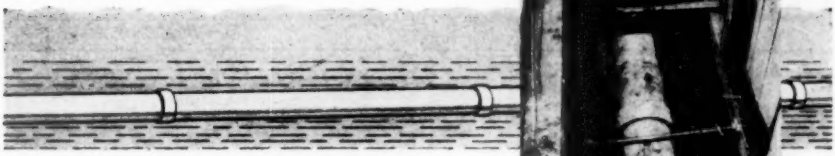
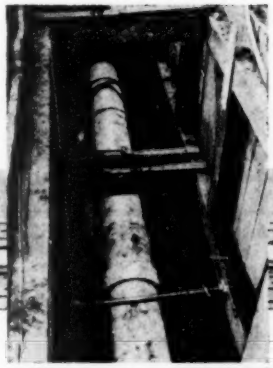
High water table?





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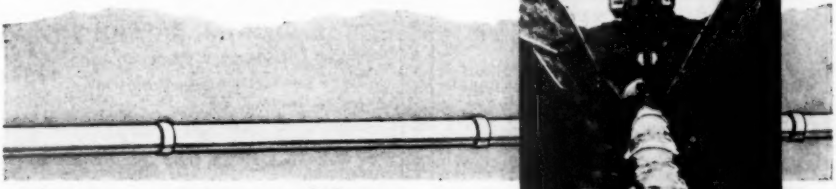

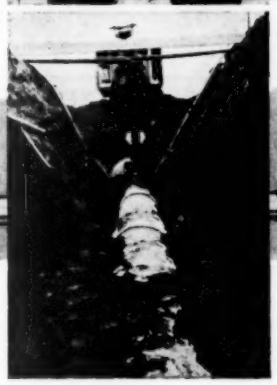

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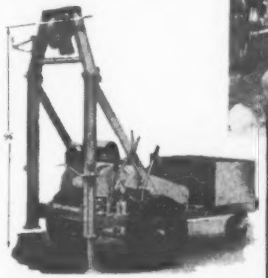

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